BETD

STUDIES ON SUBSURFACE MOVEMENT OF EFFLUENT FROM PRIVATE SEWAGE DISPOSAL SYSTEMS USING RADIOACTIVE AND DYE TRACERS

Part 2
1973-74

Ministry of the Environment

Ontario

The Honourable
William G. Newman,
Minister

Everett Biggs,
Deputy Minister

To Max Walkinshaw with compliments and thanks for perusal of the manuscript and valuable comments

Mark

Aug. 22. 75

ONTARIO MINISTRY OF THE ENVIRONMENT

STUDIES ON SUBSURFACE MOVEMENT OF EFFLUENT FROM PRIVATE SEWAGE DISPOSAL SYSTEMS USING RADIOACTIVE AND DYE TRACERS

(Part 2)

1973-74

By

Dr. M. Brandes, P. Eng.

POLLUTION CONTROL BRANCH

APPLIED SCIENCES

1975

PREFACE

by

M. B. Fielding, P. Eng.

In recent years there has been increased emphasis placed on providing efficient private waste treatment facilities, especially in cottage and recreational lake areas.

One aspect of this work has been the examination of so-called "conventional" waste treatment systems, the septic tank - tile field installations.

This report is a continuation of a previous report (Part I) and is the culmination of a study initiated in 1972 to investigate such systems and their effect on adjacent lakes.

Part 2 of the study examines an additional four systems with particular emphasis on movement of phosphorus. The methods and procedures are based on information obtained from the earlier studies.

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

INDEX

STUDIES ON SUBSURFACE MOVEMENTS OF EFFLUENT FROM PRIVATE SEWAGE DISPOSAL SYSTEMS USING RADIOACTIVE AND DYE TRACERS

(INTERIM REPORT-PART 2, 1973-74)

1. SUMMARY OF INTERIM REPORT - PART 1, 1972

The purpose of the study covered by Reports Part 1 and 2, was to determine the effect of several parameters related to the location and construction of conventional sewage disposal systems (Septic Tank - Tile Field*) on the subsurface movement of the septic tank effluent towards the receiving waters and on the concentration of chemical and bacteriological pollutants in the ground water downstream from the disposal system.

Methods and techniques used in the 1972 experimental study have been described in Part 1 in considerable detail and obtained results presented and discussed. (1)

Tritium, a radioactive isotope of hydrogen (^{3}H), radioactive phosphorus (^{32}P) and sodium fluorescein were used simultaneously for tracing the underground movement of the septic tank effluent.

When the disposal systems were built in uniform undisturbed soil containing more than 40% of silt and clay, tritium was observed to move freely through soil and it was detected in groundwater in considerable distances from the system. The study has shown that tritium is an ideal tracer which also makes possible the determination, within a known accuracy, of the velocity of ground water movement. Tritium was recommended as a tracer for studying underground movement of septic tank effluent.

---

* Tile Field also called Disposal Field or Leaching Bed.

Radioactive phosphorus, however, was not detected in the ground water beyond the tile field area, probably because either an interaction between the minute quantities of radioactive phosphorus and the soil took place or, as suggested by some authors (e.g. Hemwall (2)), a replacement took place between the phosphorus (^{31}P) from the septic tank effluent, already fixed in the soil, and the radioactive phosphorus (^{32}P) used as a tracer. Radioactive phosphorus was not recommended as a tracer for studying underground movement of wastewater.

Fluorescein used as a tracer was not detected in the ground beyond the tile field area and its use as a tracer in undisturbed soil was not recommended.

Chemical analyses of ground water taken at different distances from the tile field have shown a significant decrease in concentration of phosphorus (to about 0.3 mg/l) within a distance of 10 feet (~3.0m) from the tile field. At a distance of 6.0 feet (1.8m) from the tile field, the average concentration of phosphorus in the ground water was only 0.1 mg/l i.e. 10 times less than the concentration of phosphorus recommended as an objective for effluent from wastewater treatment plants.(3)

A satisfactory removal of faecal coliform organisms from septic tank effluent by uniform undisturbed soil was also observed. No faecal coliform organisms were detected in ground water at distances greater than 55 feet (~17m) from the tile field.

The average velocity of the underground movement of tritium in undisturbed soil containing more than 40% of silt and clay did not exceed 0.33 ft/day (0.1 m/day). Assuming the distances of the sewage disposal systems from a water body as not less than 50 feet

(~15.0m) the travel time of the septic tank effluent will not be less than 150 days, i.e. a time too long for faecal organisms to survive in an underground water environment. The undisturbed soil proved to be satisfactory for sewage disposal systems. When fill material containing stones and boulders was used for construction of the disposal system relatively high concentrations of phosphorus and high counts of faecal coliforms were detected in the ground water in distances of 50 feet (~15.0m) from the tile field and therefore the use of such kind of material for the disposal of sewage was not recommended.

2. SUMMARY OF REPORT - PART 2, 1973-4

Studies on underground movement of septic tank effluent from individual sewage disposal systems towards the receiving body of water were continued during an eleven month period between June 25, 1973 and May 21, 1974. The study was completed.

Four sewage disposal systems were studied. Three of the systems were built on clayey-silt on Lake Couchiching and one on imported sand on Little Lake.

Radioactive and dye tracers (Tritium, ^{32}P and Fluorescein) in concentrations higher than those used in the 1972 tracer study were used for tracing the underground movement of the septic tank effluent. Tritium proved again to be an excellent tracer for tracing the movement of septic tank effluent.

Radioactive phosphorus ^{32}P and Fluorescein were not detected in the ground water in concentrations higher than those in the background water samples, radioactive phosphorus and Fluorescein can not be recommended to be used as a tracer in soil.

A considerable part of the introduced radioactive phosphorus (^{32}P) and of the phosphorus (^{31}P) from the septic tank effluent was fixed in the soil. Extraction of phosphorus from soil samples by using different extracting agents have shown that the phosphorus was retained mainly in the upper layer of the soil below the tile field.

The average velocity of movement of tritium when passing through unsaturated and then in saturated clayey silt was found to be 0.54 ft/day (0.16m/day), the velocity in the saturated part of soil only (presumably the same as the velocity of the ground water flow) was 1.0 ft/day (0.3m/day).

Chemical analysis of the ground water have shown that some amount of phosphorus from the sewage disposal system is entering the ground water, however, the removal of phosphorus by the system studied was relatively high i.e. about 78% when sand was the filtering medium and about 90% when clayey-silt was used.

A drop in concentration of phosphorus in ground water with distance from the tile field was observed. In a distance of 50 ft. (~15.2m) from the tile field the concentration of phosphorus in ground water was 0.05 mg/l in the clayey silt area and 0.1 mg/l in imported sand.

No distinguishable effect of the sewage disposal system on concentration of nitrates in ground water was observed. The concentration of nitrates in ground water was far below the accepted limits for drinking water.

The concentration of free ammonia in ground water from bore holes drilled in clayey-silt was lower than from holes in sand. It seems that some part of the ammonia is retained by the soil of the finer grain size.

The removal of coliform organisms by all of the sewage disposal systems was satisfactory.

The concentrations of the chemical and bacteriological pollutants in the lake water, close to lake shore, were below or equal to the permissible concentrations of pollutants in Public Surface Water Supplies.

No adverse effect of flooding of the tile field, during the spring and fall seasons, on concentration of pollutants in ground water was observed.

I. STUDY AREAS AND TESTING RESULTS

The characteristics of each of the four lots investigated (0-1, 0-2, 0-3, B-1) and the effectiveness of the sewage disposal systems in removal of pollutants from septic tank effluent are discussed separately.

1. LOT 0-1 ON LAKE COUCHICHING

1.1 General Characteristic

In the 1973-74 tracer study, presented in this report, radioactive and dye tracers were used only in one of the lots (0-1) located on Lake Couchiching.

The site plan of estate 0-1 showing the location of the house, the sewage disposal system (septic tank and tile field), the location of the boreholes and the lakeshore are presented in Fig. 1 of Appendix I. Fig. 1a of the same appendix presents a schematic cross-section of the lot drawn parallel to the direction of the ground water movement. The soil strata, the location and depth of tile field, the lowest ground water level (on Sept. 1973) as well as the location and depth of the boreholes (B.H.) and control holes (C.H.) are shown on the drawing. The elevations shown relate to an arbitrary point near the house. The gradient of the water table is about one percent.

The sewage disposal system of estate 0-1 was constructed in Oct. 1963 and consists of a 600 gallon (2730 litres) concrete septic tank and a 3200 sq. ft. (~297 m^2) tile field. Assuming each of the four residents of the house uses approximately 60 gallons (~273 litres) of water per day, the total daily hydraulic load to the ground below the tile field is about 0.1 gal/sq ft. (3.7 l/m^2).

The daily load to the bottom of the tile field absorption trenches (5 trenches, 72 ft. long and 1.5 ft. wide at the bottom) is about 0.4 gal/sq. ft ($\sim$19.6 l/m^2)

The subsoil at the site consists of two main strata - a layer of medium to fine sand overlying a layer of clayey silt. The soil above the tile field, probably fill material, contains considerable amounts of organic matter. The mechanical and physical characteristics of the soil layers of site studied are given in Table 1, Page 8.

The direction of the groundwater flow was determined by using piezometers before drilling boreholes and confirmed later by periodic monitoring the level of the water inside the boreholes. The standard three point method was applied. The arrow on Fig. 1 of Appendix I shows the direction of the maximum velocity of groundwater movement, however, lateral, slower movements of groundwater in other directions were also observed.

Figure 1 of Appendix II presents the fluctuation of the water table in boreholes 3, 4 and 5 during the ten months period of the study. The fluctuation of water table in the other holes followed the same pattern. The levels of the drain pipes and the ground level are also shown.

It appeared that during the fall of 1973 (November) and spring of 1974 (March-April) the water table was very high (less than 0.5 ft (0.15m) below ground surface) and above the drain pipes of the tile field. In other words the tile field was flooded with ground water.

Table 1 SOIL CHARACTERISTICS

ESTATE	Est 0-1		Est 0-2		Est 0-3	Est B-1	
STRATA	Upper Layer	Lower Layer	Upper Layer	Lower Layer	Lower Layer	Upper Layer	Lower Layer
Depth of sampling point	2' (0.61m)	4'6"(1.37m)	2'(0.61m)	9'-12' (2.74-3.66m)	4'-12' (1.22-3.66m)	3'-5' (0.91-1.52m)	
Gravel (4.9-70mm) %	0	0	0	0	0	6-30	
Sand (0.075-4.9 mm) %	86	33	25-32	1-15	2-24	50-83	
Silt (0.002-0.075 mm) %	10	44	55	53-65	61-83	11-16	
Clay (0.002mm) %	4	23	13-20	21-42	14-34	-	
Effective Size D_{10}mm	0.05	-	-	-	-	-	NOT TESTED
Coeff. of uniformity Cu	8.85	-	-	-	-	-	
Liquid limit (W_l %)	-	32.5	-	-	20.8	-	
Plastic limit (W_p %)	-	19.9	-	-	16.6	-	
Plasticity index (I_p %)	-	12.6	-	-	4.2	-	
Permeability - cm/sec	-	-	$\sim 10^{-6}$	-		$\sim 10^{-3}$	
Soil type (symbol) *	sand(S)	clayey silt (CL)	sandy silt(ML)	clayey silt (CL)	clayey silt (CL to ML)	sand (S)	

* According to UNIFIED SOIL CLASSIFICATION SYSTEM

Eight boreholes 3" (76 mm) in diameter were drilled in the ground to a depth of about 1.5 ft (45.7 cm) below the water table. Six of the boreholes (B.H) were located between the tile field and lake shore and two holes, used as control holes (C.H.), were located upstream from the tile field (Fig. 1 and 1a of Appendix I). The holes were cased with plastic pipes and protected with plastic sheets in order to avoid contamination of groundwater by runoff water. The technique was described in detail in Part 1 of this report. (1)

Water samples were taken periodically from the boreholes and tested for concentration of chemical pollutants (phosphates, nitrates, free ammonia and chlorides) for faecal and total coliform organisms and for concentration of tracers (tritium, ^{32}P, and fluorescein). Results obtained are presented in Table 1 of Appendix III.

1.2 Movement of Tracers

On July 9, 1973, after 12 days of taking background samples from the boreholes, tracers were introduced into the header connecting the septic tank with the drain pipes of the tile field. The following amounts of tracers were introduced: 100 mCi of tritium (^{3}H); 30 mCi of radioactive phosphorus (^{32}P); and 10 grams of sodium fluorescein. The three tracers were mixed and diluted in 30 gallons (136 litres) of water before being introduced.

Daily sampling was continued after introducing the tracers in order to determine the velocity of the underground movement of the tracers. It took 13 days for the tritium to move the distance of 7' (2.1 m) between the edge of the tile field

and borehole 5. The average speed of movement of tritium was about 0.54 ft/day (0.16 m/day), a speed close to that observed for movement of tritium in soil on Lake Chemong (0.33 ft/day (0.1 m/day (1)) and almost the same speed of movement of tritium as observed by Merrit in sandy soil (0.58 ft/day or 0.18 m/day) (4)

A peak concentration of tritium in groundwater as high as 690 nCi/l was observed on October 18, 1973, i.e. after 100 days of movement and dilution. The calculated degree of dilution of tritium as compared with the original concentration was 10^{-3}, the natural radioactive decay of tritium was not taken into account in calculating the dilution because of its relatively long half-life (12.5 years).

The general pattern of the effect of time on concentration of tritium in borehole 5 (Fig. 1) was similar to the changes in concentrations of tritium observed in the 1973 tracer study (1) (Fig. 2). The changes in concentration follow clearly Gumbel's Standard Skewed Distribution Curve applied mainly to hydrologic phenomena (5).

On August 16, 1973, i.e. after 37 days of travelling the tritium was detected in the groundwater in borehole 7, located in a distance of 29 ft (~9.0 m) from the edge of the tile field and at a distance of 22 ft (~6.7m) from borehole 5 (in the direction of the maximum velocity of the groundwater flow).

The average speed of movement of tritium between boreholes 5 and 7, i.e. within the saturated zone was about 1.0 ft/day (0.3 m/day). i.e. very close to the speed observed in saturated soil in an other tracer study: 1 to 2 ft/day (0.3 to 0.6 m/day) (6). The calculated vertical speed of movement of

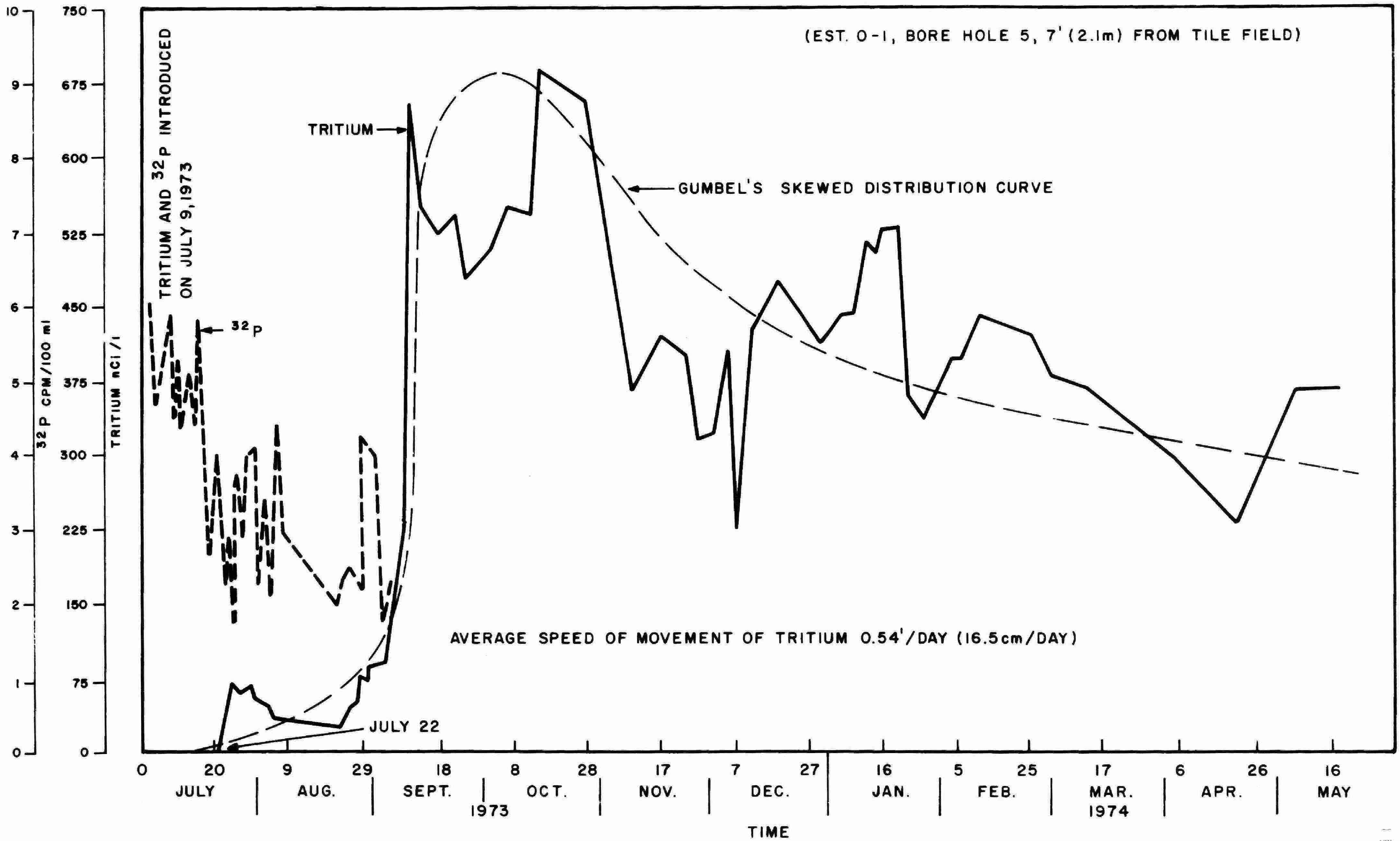


FIG. I EFFECT OF TIME ON CONCENTRATION OF TRITIUM AND ^{32}P IN GROUNDWATER

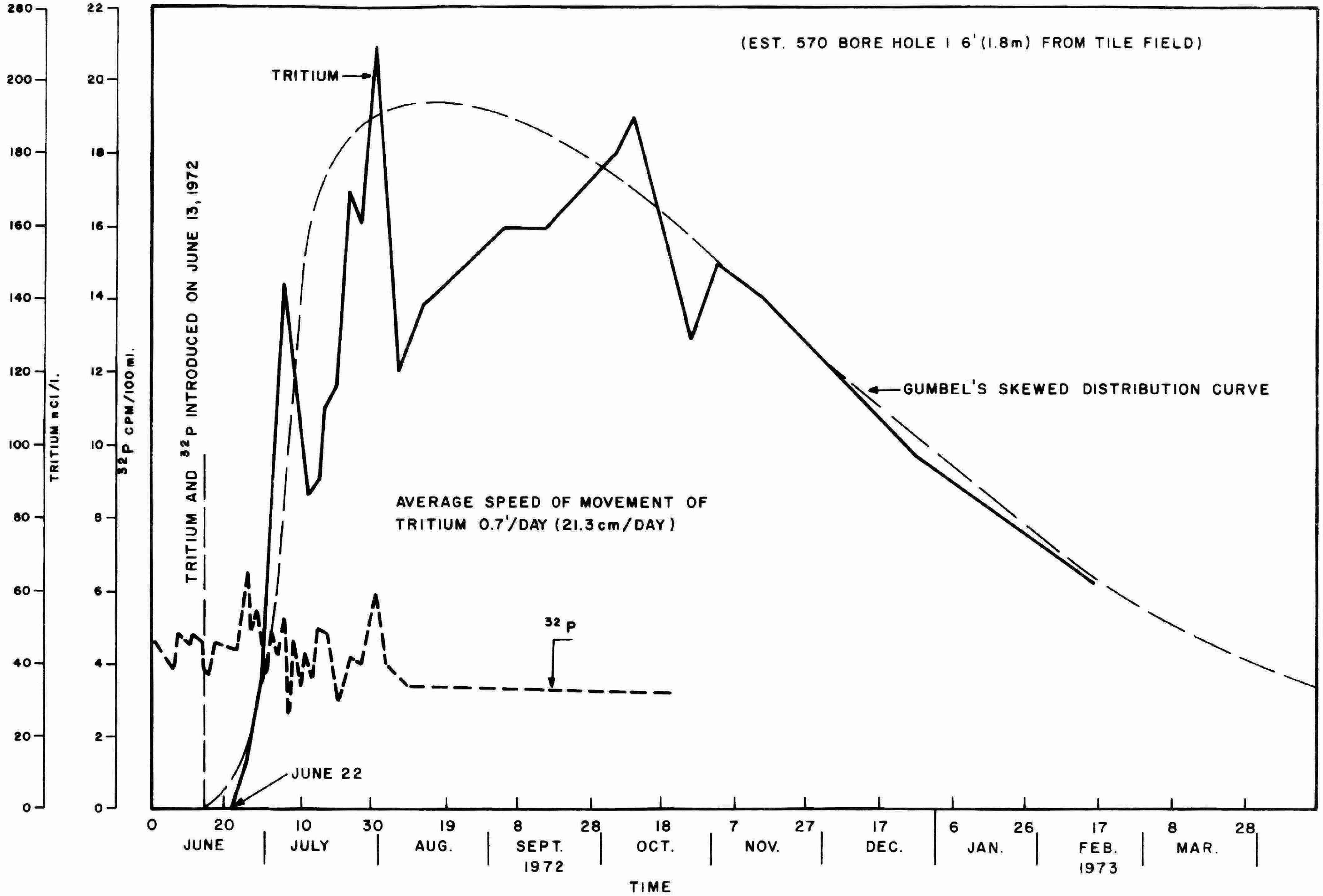


FIG. 2 EFFECT OF TIME ON CONCENTRATION OF TRITIUM AND ^{32}P IN GROUNDWATER

tritium within the unsaturated soil was about 0.59 ft/day (0.18 m/day).

In the groundwater of boreholes 3 and 4 the tritium appeared in very low concentration (not higher than 13 nCi/l) after 234 and 212 days respectively. The calculated speed of movement of tritium was about 0.03'/day (9×10^{-3} m/day). It could be assumed that the tritium did not arrive in the groundwater of boreholes 3 and 4 directly from the tile field drain pipes, it seems rather reasonable to assume that the observed, very low velocity of flow, is related to a lateral movement of tritium in groundwater from borehole 5 to the west from the main direction of the groundwater movement. From recorded water levels in the boreholes (graph 1, Appendix II), the water table in borehole 5 was for most of the time slightly higher than the water table in boreholes 3 and 4 and therefore a slow lateral movement of the groundwater from borehole 5 towards boreholes 3 and 5 could occur.

The radioactivity of ^{32}P in the water samples taken from all of the boreholes was not higher than the gross β radioactivity observed in the background water samples. The radioactive phosphorus (^{32}P) was evidently fixed in the soil. Calculations of decay and dilution of radioactive phosphorus in groundwater have shown that the ^{32}P must have been detected in the groundwater samples if no detention in soil takes place. (See calculation, Appendix IV). No tritium or radioactive phosphorus (^{32}P) was detected in water samples from the housewell or from the lake.

Also the sodium fluorescein did not reach the groundwater and was not detected in the test holes in concentrations higher than those in the background samples. During the period of study

i.e. from June 25, 1973 till March 21, 1974 a total number of 1250 water samples were tested for Tritium, ^{32}P and Fluorescein.

1.3 Efficiency in Removal of Phosphorus

The average concentration of total phosphorus in groundwater samples taken from control holes 1 and 2 was 0.05 mg/l; i.e. of the same order of magnitude as the average concentration of phosphorus in the water of Lake Couchiching (0.03 mg/l) and of the drinking water (0.01 mg/l) (See Table 1, Appendix III).

The average concentration of phosphorus in ground water samples taken from boreholes 3 to 8 located downstream from tile field, was 0.39 mg/l which indicates that some quantity of phosphorus is entering the ground water from the sewage disposal system. The increase in concentration of phosphorus in ground water due to operation of the disposal system was 0.34 mg/l, however, the total amount of phosphorus entering the lake seems to be relatively small.

Attempts were made to evaluate the amount of phosphorus entering Lake Couchiching from the sewage disposal system and, consequently to evaluate the phosphorus removal efficiency of the system.

The evaluation of the input of septic tank effluent and phosphorus into the sewage disposal system by the four residents of the house was based on the daily use of water per person - 60 gal (~273 litres) and on the concentration of phosphorus in the septic tank effluent 15 mg/l.

The estimated input was: septic tank effluent:

4 pers. x 273 l/pers.day=1092 l/day

phosphorus: 1092 l/day x 15 mg/l = 16380 mg/day

According to one ground water pollution study (7), the wastewater entering the ground from tile fields travels near the water table surface. Beek et al (8) have the opinion that the accumulation of phosphorus in soil is restricted to the upper layer of 1.3 ft (0.4m) of the soil, the author (8) presented a 96% removal of phosphorus by a land disposal system.

From measurements and observations made in this and previous studies it is concluded that an underground stream of treated and diluted wastewater is moving towards the lake inside the saturated zone of soil. The measured velocity of the stream transporting into the lake 0.34 mg of phosphorus with each litre of diluted wastewater was 1.0 ft/day (0.30 m/day). An assumption was made that the end of the stream, when reaching the lake, is 80 ft (24.5 m) wide (Figure 1 of Appendix 1) and 5 ft (1.5 m) deep. The volume occupied by the ground water in the soil was considered to be 50% of the volume of the saturated soil.

The estimated amount of diluted wastewater transporting some amount of phosphorus towards the lake and the amount of phosphorus, from the system, entering the lake was:

diluted wastewater: $24.5\text{m} \times 1.5\text{m} \times 0.30\ \text{m/day} \times 10^3\ \text{l/m}^3 \times 0.5 = 5513\ \text{l/day}$.

phosphorus: $5513\ \text{l/day} \times 0.34\ \text{mg/l} = 1874\ \text{mg/day}$

The dilution of the septic tank effluent in the ground water was:

$\frac{1092}{5513} \cong 1:5$ (i.e. one part of effluent to 5 parts of ground water)

The estimated removal of phosphorus by system 0-1 was:

$$\frac{16380 - 1874}{16380} \times 100 = 89\%$$

The observed fixation of phosphorus by the disposal system brought additional studies on concentration of phosphorus in soil samples taken from around the tile field. The soil samples were taken from depths of 2.5 ft (0.76 m) and 5.0' (1.51 m) and phosphorus was extracted by using a 0.5 N $NaHCO_3$ solution as an extracting agent. Location of soil sample points and results obtained are shown in Fig. 3. The numbers adjacent to sampling points in Fig. 3 show concentrations of phosphorus in micrograms of phosphorus per gram of dry soil. The concentration of phosphorus in soil samples from the tile field area were higher than those from samples taken from locations downstream and upstream from tile field. It seems that most of the phosphorus was fixed in the soil before the end part of the tile field area.

1.4 Efficiency in Removal of Nitrates, Ammonia, Chlorides and BOD_5

The average concentration of some contaminants (other than phosphorus) in the groundwater in the area between the tile field and the lake, as well as the concentration of contaminants in water samples taken from control holes, and from the lake and from the housewell water are shown in Table 1 of Appendix III.

The observed concentrations of nitrates and free ammonia in the groundwater were below acceptable limits for drinking water (9). The nitrate concentrations were much lower than concentrations in "near surface groundwaters" reported by Kaufman (up to 210 mg/l). (10).

The observed concentrations of chlorides in groundwater samples (30 mg/l) in the area between the tile field and lake were higher than those in the control holes (13 mg/l) but lower than the concentration of chlorides usually found in septic tank effluent

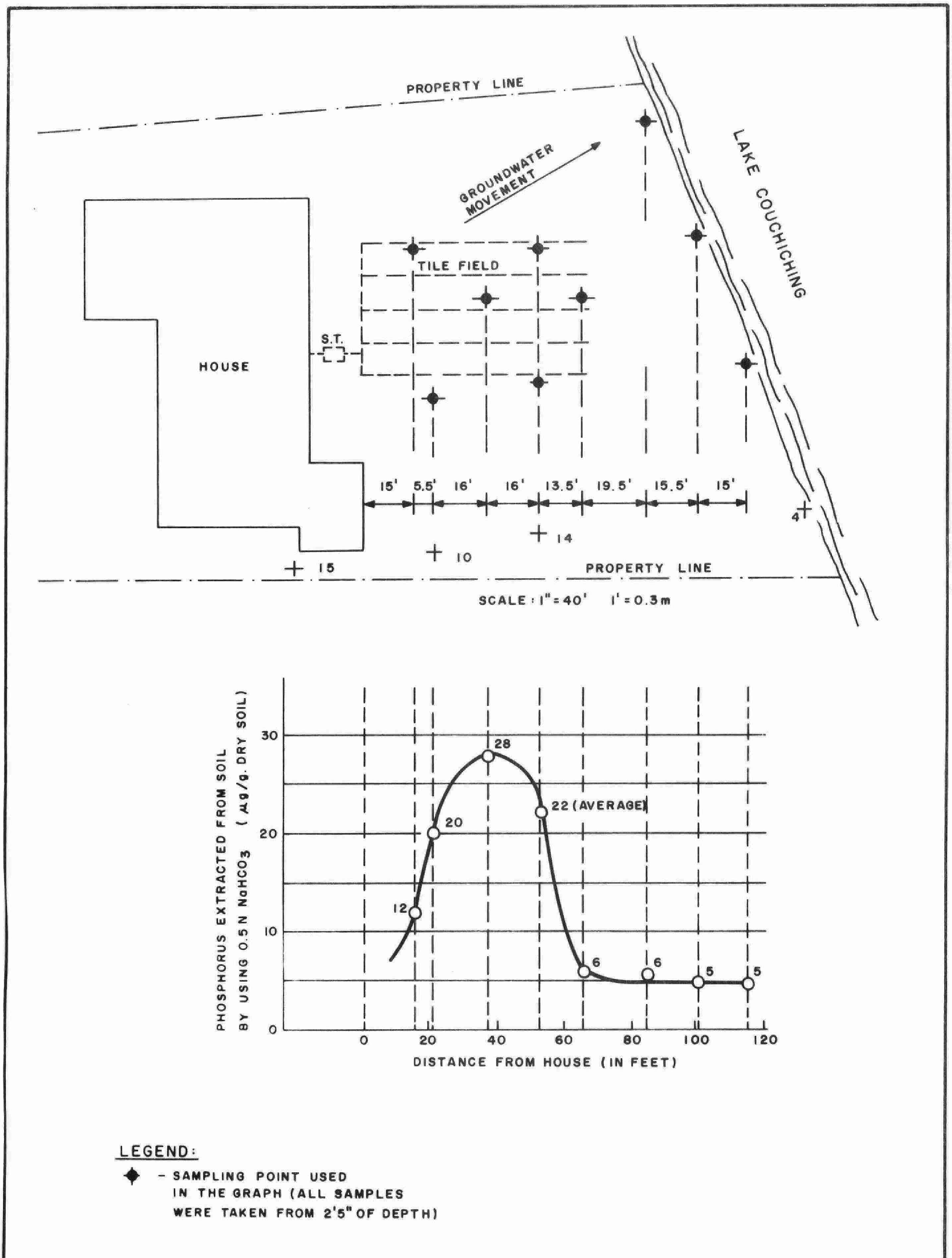


FIG. 3 PHOSPHORUS EXTRACTED FROM SOIL AROUND SEWAGE DISPOSAL SYSTEM EST. O-1 LAKE COUCHICHING

(~80 mg/l) and much lower than the permissible concentrations in drinking water (250 mg/l) (9). It seems that the chlorides are coming into the groundwater from the sewage disposal system only and not from other sources. The concentration of BOD_5 in groundwater was very low. (between 1.5 and 4.5 mg/l).

No distinct effect of distance of sample source from tile field on concentration of nitrogen, chlorides and BOD_5 in groundwater was observed.

1.5 Efficiency in Removal of Coliform Organisms.

Faecal coliform organisms identified in the groundwater indicate that the groundwater is contaminated by effluent coming from a sewage disposal system.

Water samples taken from control holes 1 and 2 have shown an average of 830 total and 48 faecal coliform organisms per 100 ml of groundwater i.e. numbers not higher than acceptable limits for coliform organisms concentrations in raw water sources of drinking water supplies (1000 total and 100 faecal coliforms in 100 ml of water). (9). Investigations of the possible sources of contamination of control hole 2 with faecal coliform organisms have shown that the neighbours' sewage disposal system could be the source

Concentrations of coliform organisms observed in control hole 1 (150 total and less than 10 faecal per 100 ml of water) seem to be rather typical for ground water in the area of Est. 0-1.

The average concentration of coliform organisms in test holes 6, 7 and 8 located downstream from tile field and close to the lake shore was 780 total and 18 faecal organisms per 100 ml of water, i.e. less than the acceptable limit for coliform

organisms in raw water sources of drinking water. The sewage disposal system of Est. 0-1 is not causing pollution of the lake water with coliform organisms.

Borehole 5 located close to tile field showed a higher concentration of coliform organisms in groundwater than other test holes (4730 of total and 920 of faecal coliform per 100 ml). The reason for higher concentrations of coliform organisms and high concentrations of tritium observed in hole 5 can be attributed to possible uneven distribution of the septic tank effluent into the drain tiles of the tile field, a phenomenon observed often in old tile fields. It appears that the header connected to the drain pipes is sloping towards hole 5, thus the septic tank effluent is penetrating the ground via distribution pipes located close to hole 5. The same conclusion was also drawn from the observed long period of time (~7 months) taken by the tritium to reach holes 3 and 4 located at a distance of only 7 feet from the edge of the tile field.

2. LOT 0-2 ON LAKE COUCHICHING

2.1 General Characteristics

The site plan of lot 0-2 showing the location of the house, the sewage disposal system, the boreholes and lakeshore are presented in Fig. 2 of Appendix I. Fig. 2a of the same Appendix presents a schematic cross-section of the lot under study drawn parallel to the direction of the groundwater movement. The soil strata, location and depth of tile field, the lowest groundwater level (on Sept. 1973) as well as the location and depth of the boreholes (B.H.) and control holes (C.H.) are shown on the drawing. The elevations shown in that figure relate to an arbitrary point near the house.

The subsoil at the site consists of two main strata: a layer of sandy silt overlying a layer of clayey silt. The upper layer is about 2.5 to 3.0 feet (0.75 to 0.90 m) in thickness and the lower layer extends to at least 12 feet (3.6 m) below the ground surface. The transition between the layers is gradual and there is a slight increase in the content of clay with depth. The characteristic of the two layers of soil is given in Table 1.

The sewage disposal system of Est. 0-2 was built in February, 1964 and consists of a 600 gallon (2730 litres) concrete septic tank and of a 900 sq. ft. (84 m^2) tile field. Assuming each of the three residents of the house uses about 60 gallons (~273 litres) of water per day, the total daily hydraulic load of the tile field is about 0.2 gal/sq.ft. (~10 l/m^2). The daily hydraulic load of the bottom of the tile field trenches (4 trenches 45 ft. long and 1.5 ft. wide at bottom) is about 0.7 gal/sq. ft. (~34 l/m^2).

During a considerable part of the study period i.e. between November, 1973 and March, 1974, the distribution pipes were flooded by groundwater. On Nov. 20, 1973 and Jan. 28, 1974 the water table in boreholes 2 and 3 was in a distance of less than one inch from the ground surface and the tile field was submerged in water (see Fig. 2 of Appendix II). Also in this case, similarly to the phenomenon observed in Lot 0-1, no adverse effect of flooding on concentration of pollutants in the groundwater was observed.

Four test holes (B.H. 3 to 6) were drilled in the ground in locations downstream from tile field and two control holes (C.H. 1 and 2) were drilled behind the house upstream from the sewage disposal system. (Fig. 2, Appendix I). Water samples were taken periodically from all the boreholes and tested for chemical and bacteriological contaminants. Results on concentration of contaminants in groundwater are summarized in table 2 of Appendix III.

2.2 Efficiency in Removal of Phosphorus

The average concentration of total phosphorus in the background water samples taken from control holes 1 and 2 was 0.05 mg/l i.e. the same average concentrations as observed in groundwater from control holes of Est. 0-1 (Table 1, Appendix III)

The average concentration of total phosphorus in the ground water from locations downstream from the tile field (test holes 3 to 6) was somewhat higher (0.09 mg/l) than in water samples from control holes, the increase (0.04 mg/l) caused by the sewage disposal system. It seems however, that the phosphorus removal effect of the sewage disposal system was extremely high.

Attempts were made to calculate the approximate phosphorus

removal by the system 0-2. Assuming the underground stream of the diluted wastewater (as described previously) is moving towards the lake with the same speed as determined in Est 0-1 (1.0 ft/day or 0.30 m/day) and assuming, for simplicity, the width and depth of the stream are also the same as in Est 0-1 the amount of diluted wastewater and phosphorus entering lake Couchiching from the sewage disposal system are:

diluted wastewater: 5513 l/day

phosphorus: 5513 l/day x 0.04 mg/l = 221 mg/day

The estimated input of septic tank effluent and phosphorus into the sewage disposal system by the three residents of the house was:

Septic tank effluent: 3 pers x 273 l/person day = 819 l/day

phosphorus: 819 l/day x 15 mg/l = 12285 mg/day

dilution: $\frac{819}{5573} = \frac{1}{6.73}$ (i.e. about one part of effluent to 7 parts of ground water).

The estimated removal of phosphorus by the system 0-2 was:

$$\frac{12285 - 221}{12285} \times 100 = 98\%$$

Soil samples taken from locations around the tile field were tested for phosphorus contents by extracting the phosphorus from soil using a 1M H_2SO_4 solution. Location of soil sampling points and results obtained are shown in Fig. 4. The numbers adjacent to sampling points in Fig. 4 show the depth from which the soil samples were taken. It was observed that the phosphorus was fixed by the soil mostly in the tile field area.

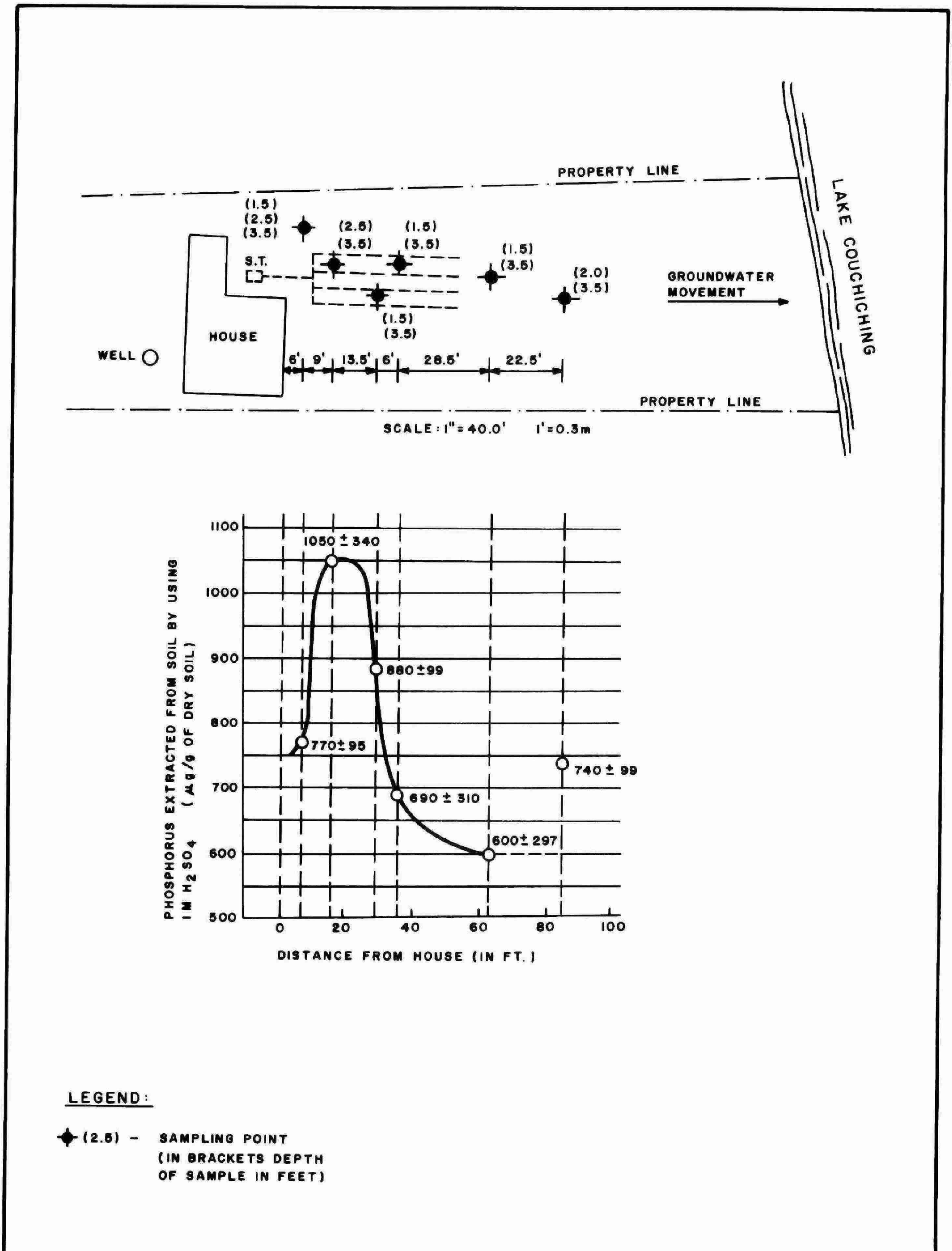


FIG. 4 PHOSPHORUS EXTRACTED FROM SOIL AROUND SEWAGE DISPOSAL SYSTEM EST. O-2 LAKE COUCHICHING

2.3 Efficiency in removal of Nitrates, Ammonia, Chlorides and BOD_5

Nitrates (N) The average concentration of nitrates in water samples from control holes 1 and 2 was 0.05 mg/l and in water samples from test holes 3 to 6 also 0.05 mg/l i.e. no increase in nitrate concentration in groundwater due to the sewage disposal system was observed.

Free Ammonia (N) The average concentration of Free Ammonia in samples from control holes 1 and 2 was 0.06 mg/l and in samples from test holes 3 to 6 located downstream from tile field was 0.15 mg/l. It seems that the sewage disposal system affects in some degree the concentration of free ammonia in groundwater but the concentration is still lower than the acceptable limit for ammonia in drinking water which is 0.5 mg/l (9).

Chlorides (Cl) The concentration of chlorides in groundwater was between 19 and 80 mg/l i.e. of the same range as usually found in the septic tank effluent (30 to 80 mg/l). No difference in concentration of chlorides in water samples taken from control holes and from test holes downstream from tile field, was observed.

High average concentration of chlorides, 47 mg/l, in water samples from the control hole and 69 mg/l in housewell water can be attributed to the vicinity of the road (see Fig. 2 of Appendix I) where chlorides are used for snow melting during the winter period. The concentration of chlorides dropped in the water samples from all of the holes during the fall and winter, when the water table becomes very high, probably due to higher dilution factor.

BOD_5 The BOD_5 concentration in the groundwater was very low(between 1.2 to 2.1 mg/l)

2.4 Efficiency in Removal of Coliform Organisms

The average concentration of total and faecal coliform organisms in water samples taken from the control holes was 424 and 16 counts per 100 ml respectively. In water samples from the test holes 3 to 6, located downstream from the tile field, the appropriate average concentrations were 1384 counts and 100 counts per 100 ml. The increase in coliform concentration was evidently caused by the sewage disposal system but even the increased concentrations of coliform organisms in the groundwater were relatively low as compared to the maximum permissible limit for raw water sources of drinking water which is 5000 total and 1000 faecal coliform organisms per 100 ml of water (9).

3. LOT 0-3 ON LAKE COUCHICHING

3.1 General Characteristics

The site plan of lot 0-3 and the profile of the ground and soil strata are shown in Figs. 3 and 3a of Appendix I.

No reliable data of the volume of the septic tank and of the area and distribution pipes of the tile field were available. For the last 2 years the sewage disposal system was used only by one person.

There are essentially two layers of soil below the ground surface: the upper layer is sandy silt with some clay and is approximately 2 to 2.5 ft (0.61 to 0.76m) in thickness. The lower soil layer is classified as clayey silt and has a larger amount of clay-sized particles than the upper one. The depth of this layer is at least 10 ft. (3.05m). The characteristic of the two layers of soil is given in Table 1.

As shown in Fig. 3 of Appendix II the distribution pipes were flooded by groundwater during a considerable part of the period of study, i.e. from November 1973 till March 1974. On November 1973 and in March 1974 the distance of the water table from ground surface was only about 4 to 11 inches (100-280mm) (see Fig. 3 of Appendix II).

No adverse effect of flooding of the tile field on concentration of phosphates or coliform organisms, in the groundwater was observed.

Four test holes (B.H. 3, 4, 5, and 6) were drilled in the ground in locations downstream from tile field and two control holes (C.H. 1 and 2) were drilled in locations upstream from sewage disposal system (Fig. 3, Appendix II). Water samples

have been taken periodically from all the boreholes and tested for chemical (phosphates, nitrates, free ammonia and chlorides) and bacteriological (coliform organisms) contaminants.

Concentration of contaminants in groundwater are summarized in Table 3 of Appendix III.

3.2 Efficiency in Removal of Phosphorus

The average concentrations of phosphorus in the water samples from control holes 1 and 2 and from the test holes 3 to 6 were less than 0.1 mg/l. (Table 3, Appendix III). No effect of the sewage disposal system on concentration of phosphorus in ground water was observed. One of the reasons for relatively low concentration of phosphorus detected in groundwater can be attributed to limited use of the sewage disposal system (one person only).

It appears that all the phosphates discharged from the system are fixed in the soil. (100% removal)

Soil samples taken from locations around the tile field were tested for phosphorus contents by extracting the phosphorus using 1M H_2SO_4 solution. Location of soil sampling points, depth of sampling points and amount of phosphorus extracted are shown in Fig. 5. The maximum concentration of phosphorus was observed in soil samples taken from locations close to edge of tile field.

3.3 Efficiency in Removal of Nitrates, Ammonia, Chlorides and BOD_5

The concentration of nitrates, free ammonia and chlorides in the groundwater was relatively low. No effect of the sewage disposal system on the concentration of nitrates and free

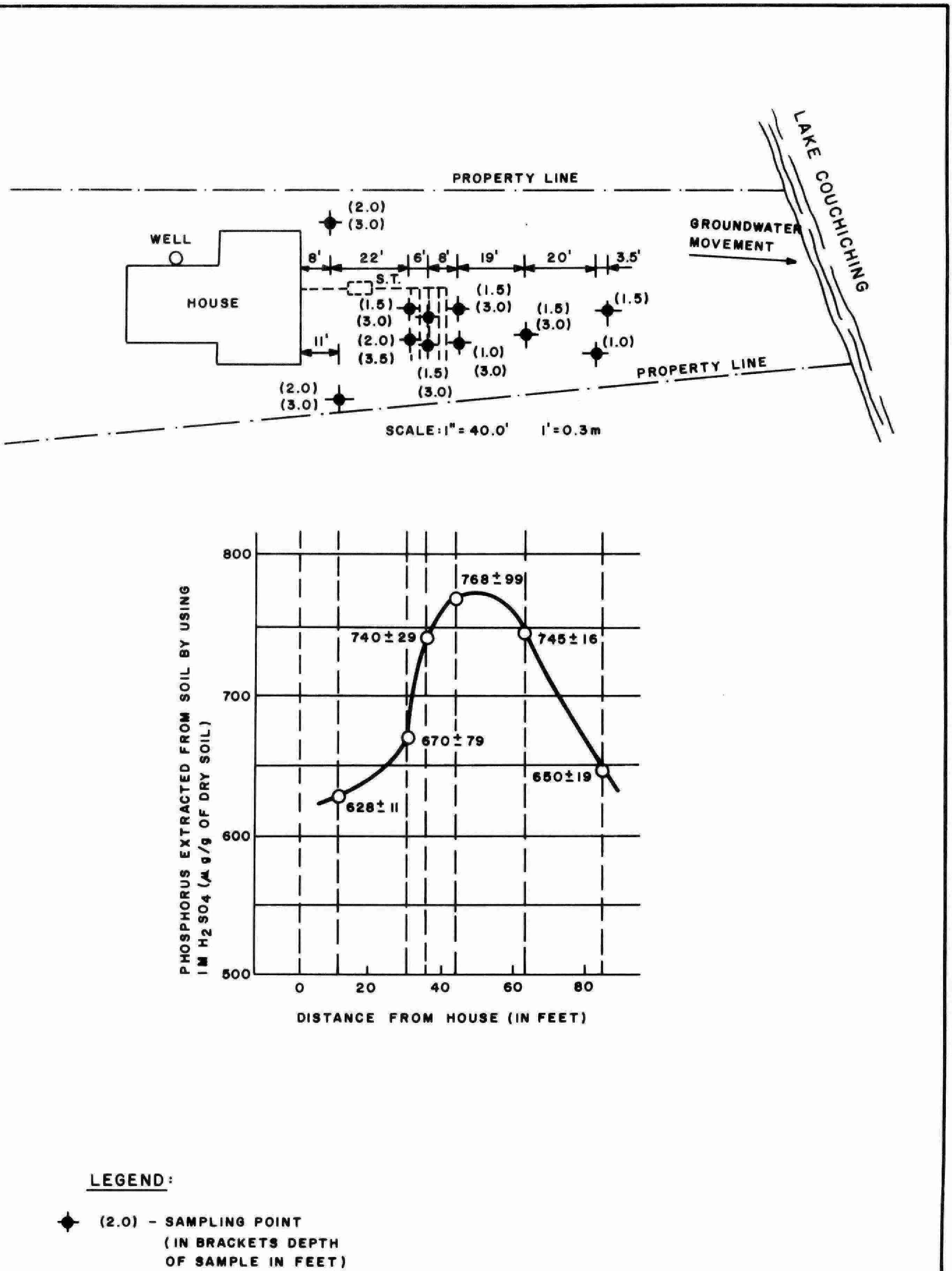


FIG. 5 PHOSPHORUS EXTRACTED FROM SOIL AROUND SEWAGE DISPOSAL SYSTEM EST. O-3 LAKE COUCHICHING

ammonia in groundwater was observed. The average concentration of chlorides in groundwater from holes located downstream from the tile field was 26 mg/l; the average concentration of chlorides in samples from control holes was only 12 mg/l. The effect of the sewage disposal system on concentration of chlorides seems to be evident.

BOD_5

The BOD_5 in groundwater was relatively low (less than 3.0 mg/l)

3.4 Efficiency in Removal of Coliform Organisms

The concentration of total and faecal coliform organisms in groundwater from control hole 2 was unusually high (4060 of total and 70 of faecal organisms per 100 ml of water). Reasons for high contamination of control hole 2 not found, but was probably due to the neighbours'sewage disposal system.

The concentration of coliform organisms in test holes 3 and 4 located at a distance of 5' (1.5m) from the edge of the tile field was also relatively high (2980 of total and 500 of faecal coliform organisms in hole 4). Boreholes 5 and 6 located at distances of 50' (15.24m) and 44' (13.41m) from the edge of the tile field respectively show relatively low contamination with coliform organisms in the ground water (see Table 3 of Appendix III).

Generally, the sewage disposal system of Est 0-3 was used only by one person for the last 2 years and that can be one of the reasons for low contamination of groundwater with chemical pollutants and with faecal coliform organisms.

4. LOT B-1 ON LITTLE LAKE

4.1 General Characteristics

The site plan of lot B-1 and the profile of the ground and soil strata are shown in Fig. 4 and 4a of Appendix I. The upper deep layer of soil in Lot B-1 was of silty sandy fill; the lower layer at a depth of more than 6 ft (1.83 m) from the surface was of clayey-silt.

The sewage disposal system of Est. B-1 was built in August 1960 and consists of a 400 gallon (1820 litres) concrete septic tank and a 1600 sq. ft. ($\sim$149 m^2) tile field. Assuming each of the three residents uses about 60 gallons ($\sim$273 litres) of water per day, the total daily hydraulic load to the ground below the tile field is about 0.1 gal/sq. ft. /day (5.5 l/m^2). The daily load to the bottom of the tile field trenches (5 trenches, 42 ft. long and 1.5 ft. wide at the bottom) is about 0.6 gal/ sq. ft. (29.4 l/m^2).

It can be assumed that the septic tank effluent is moving towards the lake mainly through the upper sandy fill layer. The characteristic of the soil layer is given in Table 1.

A considerable fluctuation of the water table was observed during the study. As is seen in Fig. 4 of Appendix II, the distribution pipes were flooded during a six months period of the year, (between the end of October 1973 till the end of April 1974). On April 8, 1974 the water table in hole 3 was only about 9" (0.23m) below ground surface. However, as in the other lots no adverse effect of flooding on concentrations of pollutants in the groundwater was observed, it seems rather that the decrease in concentration of pollutants was even greater, due probably to

higher dilution in the ground water and to the fact that much more soil took part in the filtering process. Five boreholes (B.H.) were drilled in the ground between the tile field and the lakeshore and two control holes (C.H.) were drilled upstream from the tile field. Water samples were taken periodically from the bore holes and tested for chemical and bacteriological pollutants. Results obtained are presented in Table 4 of Appendix III.

4.2 Efficiency in Removal of Phosphorus

The average concentration of phosphorus in the groundwater of lot B-1 located on Little Lake was higher than in groundwater of O-1, O-2 and O-3 located on Lake Couchiching (see Appendix III). The reason for higher concentrations of phosphorus can be attributed to the deep, pervious layer of sandy fill spread below the drain tiles of the tile field.

The average concentration of phosphorus in the groundwater of the control hole (C.H.I.) was 0.15 mg/l. In groundwater of the three test holes (B.H. 3, 4 and 5) located at a distance of about 10 ft (3.05 m) from the edge of the tile field the concentration was 0.93 mg/l and in the two test holes (B.H. 6 and 7) located in a distance of about 50' (15.24 m) and 60' (18.29m) from the edge of the tile field the average concentration was 0.23 mg/l. An apparent decrease in concentration of phosphorus in ground water with distance from tile field was observed. The average concentration of phosphorus in ground water samples taken from test holes 3 to 7 was 0.63 mg/l (see table 3) an increase of 0.48 mg/l in comparison with the concentration in background samples the increase due to operation of the sewage disposal system.

An attempt was made also to calculate roughly the amount of phosphorus entering Little Lake from B-1 disposal system using the way of calculation as described previously.

Diluted wastewater entering Little Lake-5513 l/day,

phosphorus entering Little Lake-5513 l/day x 0.48 mg/l

=2649 mg/day

The estimated daily input of septic tank effluent and phosphorus into the sewage disposal system by the three residents of the house was:

Septic tank effluent: 3 pers. x 273 l/person day = 879 l/day

Phosphorus: 879 l/day x 15 mg/l = 12285 mg/day

Dilution: about 1:7 (about one part of effluent to 7 parts of ground water)

The estimated removal of phosphorus by the system B-1 was:

$$\frac{12285 - 2649}{12285} \times 100 = 78\%$$

In order to determine whether the phosphorus removed by the system from the septic tank effluent is fixed in the soil, soil samples were taken from around the tile field and phosphorus was extracted from the soil by using 0.5N $NaHCO_3$ and 1M H_2SO_4 as extraction agents.

The amount of phosphorus extracted from the soil samples taken from different locations and depths are shown in Fig. 6.

The background soil samples taken from locations upstream from tile field show much lower contents of phosphorus than those samples taken from the tile field area. The highest concentration of phosphorus was observed in soil samples from locations close to the end of the drain tiles. Downstream from tile field in a

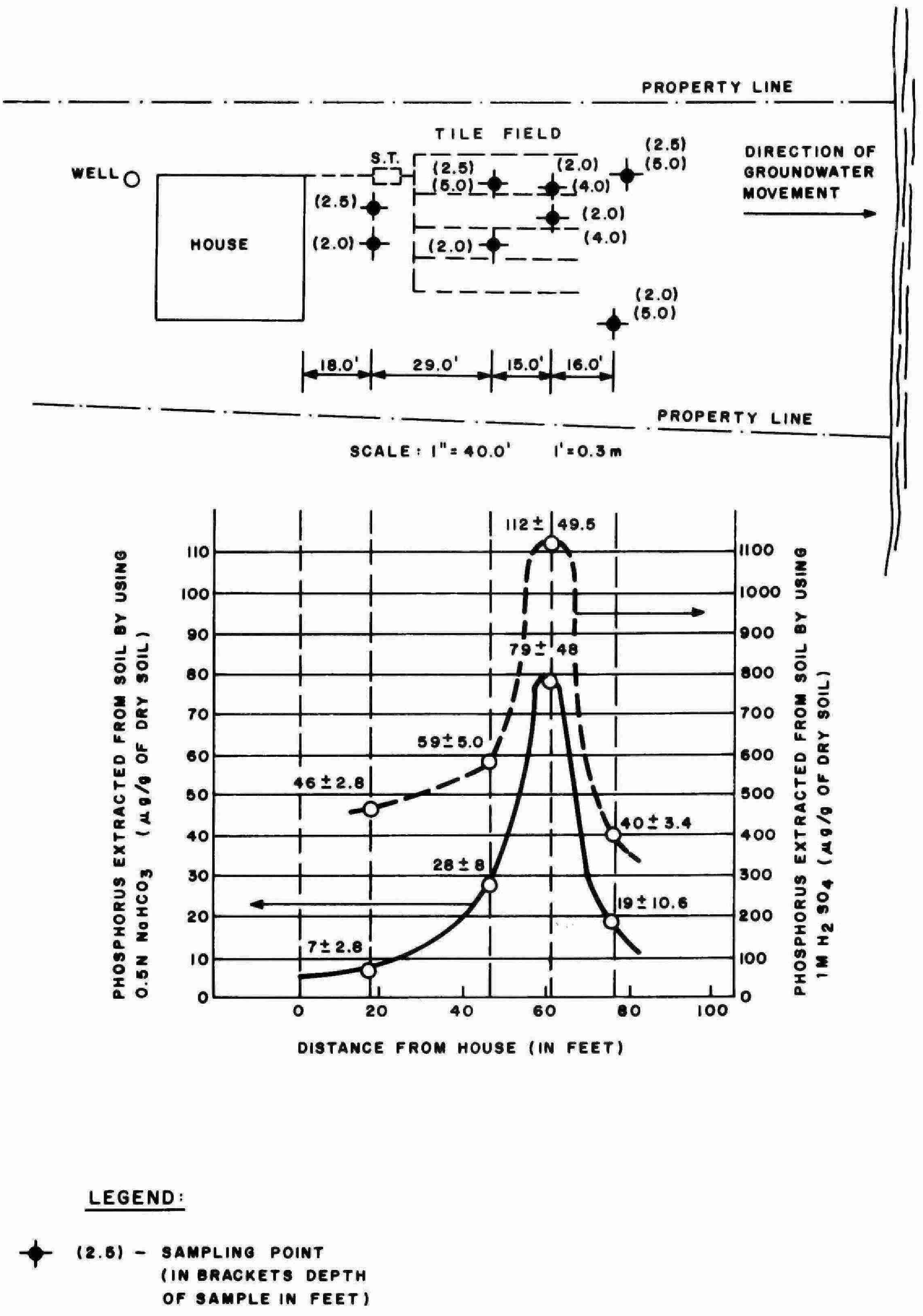


FIG. 6 PHOSHORUS EXTRACTED FROM SOIL AROUND SEWAGE DISPOSAL SYSTEM EST. B-1 LITTLE LAKE

distance of only 10 ft (3.0 m) from tile field the concentrations of phosphorus in soil was again low. The phosphorus is fixed mainly in the unsaturated part of soil in the tile field area.

The maximum concentration of phosphorus in soil was observed in locations close to the end of the distribution pipes. It was also observed that in 11 soil samples (of 13 samples tested) the concentration of phosphorus was higher in samples taken from upper layers: 2.0 to 2.5 ft (6.1 to 6.7 m) from the ground surface. This indicates that the phosphorus is fixed mainly in the upper layers of soil below the distribution pipes.

Similar observations on phosphorus distributions with depth of soil were reported by Beek et al (8).

4.3 Efficiency in Removal of Nitrates, Ammonia Chlorides and BOD_5

The average concentration of nitrates in the background water samples from control holes was 0.03 mg/l. In the ground water samples from test holes 3, 4, and 5, located at a distance of about 10 to 14 feet (3.0 to 4.3 m) from the tile field the average concentration was much higher (0.51 mg/l) than in the control holes and of the same order as usually observed in septic tank effluent (0.06 to 0.1 mg/l). It is relevant that the concentration of nitrates in final effluent from sand filters, where air is easily accessible, is about 18 to 30 mg/l (11). The aerobic conditions in the sand filters promote faster oxidizing of ammonia to nitrates than the oxidizing occuring in compact and saturated sand.

Despite a permanent process of dilution of nitrates taking place when the septic tank effluent enters the ground water the

concentration of nitrates continued to be as high as in the septic tank effluent. A resupply of nitrates must have been taken place as a result of the process of oxidizing ammonia into nitrates going on mostly within the unsaturated part of the soil below the tile field.

Attempts were made to determine the effect of flooding on the speed of the oxidizing process of ammonia but only in some cases was it observed that the oxidizing process is inhibited by the flooding.

Chlorides

A drop in concentration of chlorides in ground water with distance from tile field was observed. The reason for relatively high concentrations of chlorides (117 mg/l) in the control hole (C.H.1) and in test hole 3 (126 mg/l) was not found.

4.4 Efficiency in Removal of Coliform Organisms

The concentration of total and faecal coliform organisms in the groundwater was low. The lake water containing 890 counts total and 30 counts faecal coliform organisms was suitable for recreational purposes (12)

II. DISCUSSION OF RESULTS

5. Concentration and Movement of Pollutants in Ground Water

5.1 General

During the testing period, from June 25, 1973 to May 21, 1974 the subsurface movement of effluent from four sewage disposal systems was under study. Three of the systems (0-1, 0-2 and 0-3) located on Lake Couchiching were built on ground consisting of two main strata: sand or sandy silt overlying a layer of clayey silt; the fourth system (B-1), which was located on Little Lake, was built on a layer of imported sandy fill overlying a layer of clayey silt. The maximum distance from ground surface to water table was 6.0 ft (1.8m) for systems at Lake Couchiching and 3 ft (0.9m) for the system on Little Lake. The distance between the tile field and the lake shore was about 50 ft (15.2m) for system 0-1 and more than 75 ft (22.9m) for the three other systems. (see Appendix I).

During the 11 months period of the study the fluctuation of the level of the water table was between 2 and 5 ft. (0.6 to 1.5m). For most of the time the drain tiles of the tile field were submerged in ground water and in some cases the water table was at a distance of only some inches from the ground surface. (see Appendix II)

No adverse effect of the flooding on the quality of the ground water was observed, probably because additional dilution of the septic tank effluent in ground water took place and because of additional volumes of saturated soil being involved in the sewage treatment process. However, no firm conclusions can be drawn from the above observations, which could suggest neglecting the required vertical distances between the bottom of the absorption trenches and

the water table. More tests are required.

The distances of tile fields from the lake shore and the volumes of the septic tanks studied met requirements for Ontario Septic Tank Systems (13).

The hydraulic load of the bottoms of the absorption trenches was between 0.4 to 0.7 gal/sq. ft. day (19.6 to 34.3 l/m^2 day) and the average hydraulic load of the area below the tile fields was between 0.1 and 0.2 gal/sq. ft. day (4.9 to 9.8 l/m^2 day). The direction of the ground water movement shown on site plans (Appendix I) was established by monitoring the level of the water table in the bore holes and the flow was found to be directed towards the lake almost perpendicularly to the lake shore.

A total number of 3330 groundwater samples were taken from 27 specially cased and protected boreholes and tested for phosphates, nitrates, free ammonia, chlorides, BOD_5, for total and faecal coliform organisms and for tritium, ^{32}P and fluorescein. The samples were analysed for chemicals (4436 tests) and for coliform organisms (1050 tests) by the Ministry of the Environment Laboratories, Resources Road, Toronto and for radioactivity and fluorescein concentration by the Ministry of Health Radiation Protection Laboratory in Toronto (1250 tests). Summarized results on concentrations of chemical and bacteriological pollutants in ground water are shown in Tables 2 and 3. (Pages 38 and 39)

Soil samples were taken from locations around the tile fields areas and tested for mechanical and physical properties by the Soil Laboratory of the Ministry of the Environment (approximately 80 samples), and for concentration of phosphorus in soil tested by Laboratory Branch of the Ministry of the Environment (approximately

Table 2 Concentrations of Chemical and Bacteriological Pollutants in Septic Tank Effluent, in Groundwater and in Lake and Housewell Water. (Establishments 0-1, 0-2 and 0-3, Average Data)

Sample Source (see Figs of Appendix I)		Phosphates (as P)		Nitrates (as N)		Free Amm. (asN)		Chlorides (as Cl)		BOD_5		Coliform Organisms 1000 /100 ml		
	Ns	Total (mg/l)	Soluble (mg/l)	Ns	mg/l	Ns	mg/l	Ns	mg/l	Ns	mg/l	Ns	Total	Fecal
Septic Tank Effluent		10-20			0.1-0.8		10.0-50.0		30.0-80.0		90-250		$20x10^6$	0.2 to $2.0x10^6$
Ground Water: Control Holes	223	0.05	<0.01	230	0.48	224	0.07	184	24	130	1.59	231	1.41	0.03
Ground Water: Test Holes	445	0.15	<0.02	503	0.25	501	0.12	405	34	293	2.08	523	1.20	0.15
Lake Couchiching	59	0.07	0.02	64	0.04	61	0.05	45	14	28	2.30	68	0.47	0.08
Housewell	43	0.02	<0.01	31	0.03	43	0.02	24	40	14	0.50	46	0.12	*
Guidelines and Criteria for Water Quality (permissible) (12)		-	-		10.0		0.5		250		-		5.0	0.5
Canadian Drinking Water Standards(9) (acceptable)		0.07	-		<10.0		0.5		250				0	0

Ns-number of sample, *--not detected or less than 10 counts/100ml.

Table 3 Concentrations of Chemical and Bacteriological Pollutants in Groundwater, Lake and Housewell Water. (Establishment B-1, Average Data).

Sample Source (see Fig. 4 & 4A of Appendix I)	Phosphates (asP)			Nitrates (as N)		Free Amm. (as N)		Chlorides (as Cl)		BOD_5		Coliform Organisms 1000/100 ml		
	Ns	Total (mg/l)	Soluble (mg/l)	Ns	mg/l	Ns	mg/l	Ns	mg/l	Ns	mg/l	Ns	Total	Fecal
Ground Water control holes	31	0.15	0.05	32	0.03	32	1.54	28	117	15	1.60	4	0.15	*
Ground Water test holes	137	0.63	0.16	145	0.35	146	1.26	134	58	134	4.38	164	0.27	*
Little Lake	11	0.07	0.01	11	0.07	11	0.06	11	21	8	3.20	12	0.89	0.03
Housewell	-	-	-									2	0.04	*
Total Samples	179			188		189		173		157		182	1068	
Septic Tank Effluent		10 to 20			0.1-0.8	10.0 to 50.0			30 to 80		90 to 250		$2x10^4$	$0.2x10^3$ to $2.0x10^3$
Public Surface water supplies (12) (permissible)		-	-		10.0		0.5		250	-	-		5.0	0.5
Drinking Water Standards (9) (acceptable)		0.07	-		10.0		0.5		250				0	0

Ns - number of samples, * - not detected or less than 10 counts/100ml

70 samples). Results of soil tests are shown in Table 1 and on Figs. 3, 4, 5 and 7.

5.2 Movement of Radioactive and Dye Tracers

Restricted use of radioactive materials in the cottage sites required by the licencing authorities (Atomic Energy Control Board - Ottawa), required careful selection of sites by the research group and the reluctance of some cottage owners to have radioisotopes introduced into their sewage disposal systems made it difficult to use radioactive tracers.

Tritium, radioactive phosphorus (^{32}P) and Fluorescein were introduced during the 1973-74 experimental study into only one of the sewage disposal systems (0-1).

As in the 1972 tracer study, where radioactive and dye tracers were used in eleven cottages, the use of tritium appeared again to be the most practical in tracing the subsurface movement of wastewater and in determining the velocity of the groundwater movement. The average velocity of tritium when moving partially in unsaturated and partially in saturated sandy silt was found to be 0.54 ft/day (0.16 m/day). The velocity of tritium in the saturated part of soil, presumably the same as the velocity of the ground water, was 1.0 ft/day (0.3 m/day).

The radioactive phosphorus (^{32}P) used in this study in a concentration 60 times higher than in the 1972 study, was not detected in the ground water of any of the boreholes. Failing to detect ^{32}P can be explained either by an interaction between the minute quantities of the ^{32}P and the soil or, as suggested by some authors (see Hemwall (2)), a replacement takes place between the phosphorus (^{31}P) already fixed in the soil and the radioactive

phosphorus (^{32}P) used as a tracer.

Simple calculations, taking into account the natural radioactive decay and the dilution of ^{32}P in the ground water, have shown that the ^{32}P would have been detected in the groundwater if no detention of a considerable part of the phosphorus in the soil takes places. (see Appendix IV)

The flourescein tracer did not appear in groundwater in concentrations higher than concentration in the background water samples and it can not be recommended for use as a tracer of underground movement of wastewater.

5.3 Concentration and Movement of Phosphorus in Groundwater and Soil

The concentration of phosphorus in groundwater downstream from the tile fields was, in most of the cases, higher than in the background water samples taken from control holes (see Tables 4 and 5 of Appendix III), indicating that some part of the phosphorus from the sewage disposal system is entering the groundwater. However, when comparing the effect of the disposal systems on the increase in concentration of pollutants in groundwater it was observed that the increased concentration in phosphates (i.e. concentration in test holes minus concentration in control holes) was proportionally lower than that of the increased concentration in chlorides. For the disposal systems 0-1, 0-2 and 0-3 the relation between the concentration of phosphorus in the septic tank effluent and the increase in concentration of phosphorus in the groundwater,(due to the effect of the disposal system), was 100 to 200 when the same relation for chlorides was only 3 to 8. (Table 2). It can be concluded that proportionally less phosphorus entered the ground

water because a considerable part of the phosphorus was fixed within the filtering medium between the distribution pipes and the test holes.

A drop in concentration of phosphorus in groundwater with distance from tile field was observed (Fig. 7). In clayey silt a drastic drop in concentration from about 10-20 mg/l in the septic tank effluent to a concentration less than 0.1 mg/l in ground water took place within the first 10' feet (3.05 m) from tile field, a phenomenon observed previously in uniform soil containing more than 40% of clay and silt. (see Fig. 5 of Interim report, Part I). In a distance of above 55 ft (16.76 m) from the tile field no concentrations of phosphorus higher than 0.15 mg/l were observed in groundwater when clayey silt was the soil used as a filtering material.

When sandy fill material was used as a filtering medium (lot (B-1)), the drop in concentration of phosphorus in groundwater was not so abrupt as in clayey silt and in a distance of 65 feet (19.81 m) from tile field there were samples with a concentration of phosphorus in groundwater as high as 0.37 mg/l, a concentration still less than half the concentration of phosphorus (1.0 mg/l) recommended by the Canada-United States Agreement on Great Lakes Water Quality as an objective for effluent from wastewater treatment plants.(3).

The average concentrations of total phosphorus in Lake Couchiching and Little Lake was 0.07 mg/l i.e. not higher than the acceptable concentrations of phosphorus in drinking water (9) and almost the same concentrations as observed in waters of Lake Ontario (0.075 mg/l) and Lake Erie (0.061 mg/l) in 1963-64 (14).

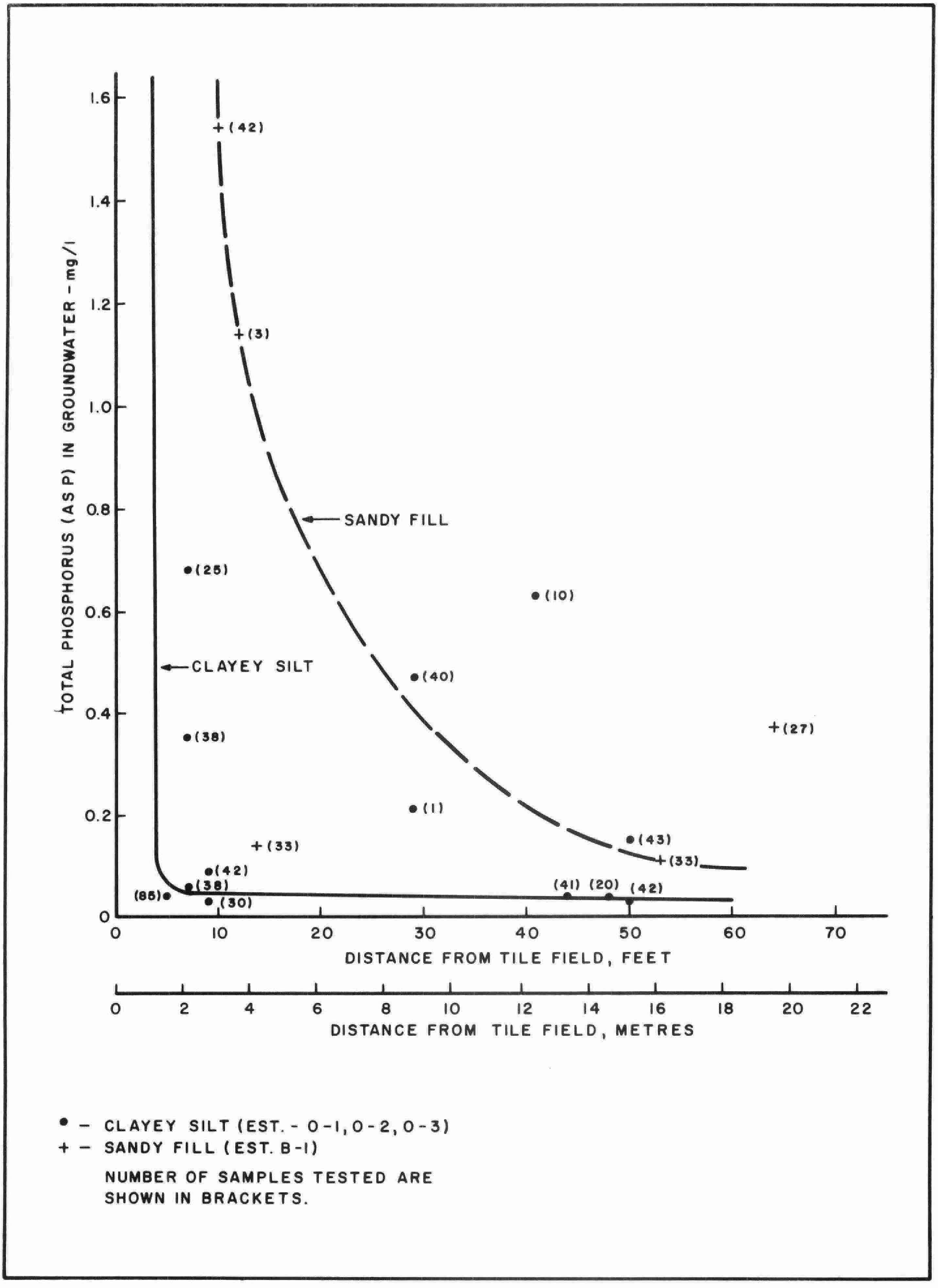


FIG. 7 THE EFFECT OF DISTANCE FROM TILE FIELD ON PHOSPHORUS CONCENTRATION IN GROUND WATER

Extraction of phosphorus from soil samples by using 0.5N $NaHCO_3$ and 1M H_2SO_4 has shown that soil samples taken from the tile field area contain more phosphorus than the background soil samples considered not to be contaminated by the septic tank effluent and also more than in soil samples taken from locations downstream from the tile field (see Figs. 3, 4, 5, 6). It is obvious that the phosphorus from the septic tank effluent is fixed in the soil mainly in the tile field area and within about 10 to 15' (3.05 to 4.57 m) downstream from the tile field. Most phosphorus was fixed in the upper layers of the soil. The phosphorus removal by the sewage disposal system built on clayey silt was 89 and 98%, the removal of phosphorus by the system built on sandy fill was only 78%.

5.4 Concentration of pollutants, other than phosphates, in ground water. Nitrates.

No distinguishable effect of soil quality and distance from the field on concentration of nitrates in groundwater was observed. In some cases (est. 0-1, 0-3) the concentration of nitrates in test holes located downstream from tile field was less than that in groundwater samples taken from control holes. (Tables 1-4 Appendix III). The concentration of nitrates in groundwater were much lower than the accepted limits for drinking water (<10.0 mg/1, as N).

Ammonia in ground water

The concentration of ammonia which is usually about 17 to 50 mg/1 in the septic tank effluent drops considerable in the groundwater due to the oxidation process taking place inside the upper layers of soil and due to dilution in groundwater. In most of the groundwater samples the concentration of free ammonia was

less than 1.0 mg/l. In the groundwater downstream from the disposal systems located on Lake Couchiching the concentration of free ammonia was less than the acceptable limits for drinking water (0.5 mg/l) (9), but in the ground water downstream from the systems located on Little Lake the concentrations of free ammonia was higher than 0.5 mg/l.

Chlorides in ground water

According to literature (15) and to measurements the concentration of chlorides in the septic tank effluent is usually from 30 to 80 mg/l. The observed average concentrations of chlorides in groundwater samples taken from some test holes (e.g. B.H. 3 of est. 0-3 of est B-1) and even from one of the control holes (C.H. 1 of est B-1) was higher than the concentrations in the septic tank effluent (see Table 1 to 4, Appendix III) but still below acceptable limits in drinking water (250 mg/l) (9).

As chlorides move easily through soil (16) it can be assumed that the chlorides detected entered the groundwater from other sources than the septic tank, probably from the road deicing salts used during the winter period. The drop in concentration of chlorides with the increase of distance from roads and tile fields is presumably due to increasing dilution in groundwater. The highest concentrations of chlorides (up to 126 mg/l) were observed in groundwater below the sewage disposal system of Est. B-1 where imported sand fill was used as a filtering medium. Generally, it was observed that inside imported sand the chlorides, like other pollutants, move more easily towards the groundwater than in original undisturbed soils of est. 0-1, 0-2, 0-3. The average concentration of chlorides in water samples from Lake Couchiching

was 14 mg/l in water samples from Little Lake the average concentration of chlorides was 21 mg/l.

BOD_5 in Groundwater

The BOD_5 concentration in groundwater downstream from the sewage disposal systems located on Lake Couchiching was very low i.e. between 1.0 to 4.5 mg/l (average 2.1 mg/l); in ground water downstream from the sewage disposal system of Est. B-1 where sand fill was used, the concentration of BOD_5 was higher (max. 11.8 mg/l in test hole 4).

Coliform Organisms in Groundwater

The removal of coliform organisms from the septic tank effluent by all of the sewage disposal systems investigated was good. In all cases the concentrations of total and faecal coliform organisms in the groundwater and in the lake water did not exceed the permissible concentrations for coliform organisms in Public Surface Water Supplies (5000 of total and 500 of faecal coliform counts in 100 ml of water (12). The concentration of faecal coliform organisms in the groundwater downstream from the sewage disposal systems was higher than in the background water samples from control holes. This indicates that some number of coliform organisms from the system is entering the groundwater but in most cases the coliform organisms do not reach the lake water.

III Conclusions

6.1 The general objective of this study was to determine the effect of some factors related to conventional septic tank systems, e.g: distance of the system from receiving waters; ground water depth; soil type; sewage travel time; on sewage treatment efficiency of the system.

During a period of about eleven months ground water samples were taken regularly from cased and protected bore holes located upstream and downstream from tile fields and tested for concentrations of chemical and bacteriological contaminants in water. Radioactive and dye tracers were also used for studying the direction and velocity of movement of the contaminants.

The principal observations and conclusions are summarized as follows:

6.2 Tracers

The use of Tritium and radioactive phosphorus (^{32}P) in concentrations much higher than those used in the 1972 tracer study has shown again that tritium is an excellent tracer for tracing underground movement of septic tank effluent. The changes in concentration of tritium at a given point in the ground water followed Gumbel's Standard Skewed Distribution Curve. The radioactive phosphorus was not detected in the groundwater in concentrations higher than those in the background samples probably because either an interaction between the minute quantities of radioactive phosphorus and the soil took place or a replacement took place between the phosphorus (^{31}P) from the septic tank effluent already fixed in the soil and the radioactive phosphorus (^{32}P) used as a tracer. Radioactive phosphorus is not a suitable tracer for tracing under-

ground movement of septic tank effluent in soils because the phosphorus is fixed in the soil.

Fluorescein was not detected in the ground water in concentrations higher than in the background samples and it can not be recommended as a tracer for tracing the movement of wastewater in soils.

6.3 Phosphorus Removal

The use of radioactive phosphorus (^{32}P) has shown that a considerable part of the radioactive phosphorus was fixed in the soil.

Chemical analysis of the groundwater has shown that some amount of phosphorus from the septic tank effluent is entering the groundwater, however, the removal of phosphorus by the disposal systems studied was relatively high, 89% to 98% removal by the systems on Lake Couchiching (clayey silt) and about 78% removal by the disposal system on Little Lake (sandy fill). Extraction of phosphorus from soil by using different extracting agents (0.5N $NaHCO_3$ or 1M H_2SO_4)has shown that the phosphorus was retained mostly in the upper layers of the soil below the tile field.

The concentration of phosphorus in groundwater dropped with distance from the tile field; the amount of the drop depends on the soil in which the sewage disposal system is built. When an organic sandy silt layer was spread on clayey silt the concentration of phosphorus in groundwater was only about 0.05 mg/l at a distance of 50 ft (15.2 m) from the tile field; when sandy material was the filtering medium the concentration of phosphorus in groundwater dropped to 0.1 mg/l at the same distance from tile field.

The concentration of total phosphorus 0.07 mg/l in water

samples from Lake Couchiching and Little Lake taken close to lakeshore was approximately the same as reported for waters of Lake Ontario (0.075 mg/l) and Lake Erie (0.061 mg/l) in the early ninteen sixties (14). According to the Canadian Guidelines for Water Quality Objectives and Standards (17) the degree of degradation of the quality of water close to lake shore of Lake Couchiching and Little Lake can be classified as between moderate and dangerous. At the middle of the lakes the quality of the water is assumed to be better.

6.4 Nitrogen Removal

No effect of the sewage disposal systems on concentration of nitrates in groundwater was observed. The concentrations of nitrates in water samples from control and test holes were much below the acceptable concentrations of nitrates in drinking water.(9).

6.5 Ammonia Removal

The concentrations of free ammonia in groundwater close to the tile fields were, in most cases, higher than those in groundwater from control holes but still below the acceptable limits for ammonia in drinking water - 0.5 mg/l (9). In groundwater below the sand fill of system B-1 the concentration of ammonia was higher than in groundwater below organic sandy silt of systems 0-1, 0-2, 0-3.

6.6 Movement of Chlorides

The average concentrations of chlorides in the groundwater samples taken from locations close to tile field were, in all cases higher than in the background water samples which indicates an effect of the sewage disposal system on contamination of the groundwater with chlorides. A decrease in concentration of chlorides in groundwater with distance from tile field was observed presumably

due to dilution of the chlorides in groundwater.

Concentrations of chlorides higher than usually observed in septic tank effluents were found in the groundwater below the sandy fill of est B-1. It is assumed that additional chlorides are entering the groundwater from the road, where deicing salts were used, or from other sources not detected.

6.7 BOD_5 in Groundwater

The BOD_5 of the groundwater samples was very low i.e. between 1.2 and 11.8 mg/1 (average 2.3 mg/1).

6.8 Coliform Organisms in Groundwater

A considerable removal of total and faecal coliform organisms by all of the four sewage disposal systems was observed.

The average concentration of total and faecal coliform organisms in groundwater samples taken from control holes of the first three sites, where the sewage disposal systems are built on medium and fine sand with some clay, was 1410 and 30 per 100 ml of water respectively. The average concentration of total and faecal coliforms in the groundwater downstream from the tile fields of the same sites were 1200 and 150 respectively. The total coliform organisms entering the groundwater from different sources (e.g. soil) are not good indications of contamination of the groundwater by the sewage disposal system. However, the increase in number of faecal coliform organisms in the groundwater downstream from tile field indicates clearly that the sewage disposal systems are the source.

Similar data were obtained for the site B-1 where the sewage disposal system was built on sandy fill material: the average concentrations of total and faecal coliform organisms in the background

water samples were 150 and 10 counts per 100 ml respectively. In the groundwater, downstream from tile field, the average concentration of total and faecal coliform organisms for the same site (B-1) were 270 and 140 per 100 ml of water respectively.

Generally, in all of the sites studied the average concentration of coliform organisms in ground water downstream from the tile field was lower than the permissible concentration of coliform organisms in Public Surface Water Supplies.

The drinking water wells, all of them located upstream from sewage disposal systems, were not affected by the system. No tritium or radioactive phosphorus was detected in the drinking water.

The average concentration of total and faecal coliform organisms in lake water samples, taken very close to lake shore, were 184 total and 70 faecal coliform counts in 100 ml of water, i.e. less than the maximum limit of total and faecal coliform concentrations in water for direct contact recreation (1000 total and 100 faecal/100 ml of water).

6.9 Effect of Flooding of the Adsorption Trenches on Concentration of Pollutants in Ground Water

For a considerable part of the time of this study the water table was above the drain tiles of the leaching beds. However, no adverse affect of the flooding on removal of pollutants from the septic tank effluent was observed. Higher dilution of the septic tank effluent in groundwater is considered to be one of the reasons of the observed decrease in concentration of contaminants. The other reason could be related to the soil conditions. As was shown in Part I of this study (Report I, Fig. 4 and 5 and also

in this study (Fig. 7)), the efficiency of the saturated part of soil in removal of chemical and bacteriological pollutants from septic tank effluent was lower than that of the unsaturated part. However, in case of flooding the volume of the unsaturated soil, existing usually between the absorption trench and the water table, is being reduced to zero; a much more voluminous part of saturated soil, not used before flooding in the treatment process, becomes involved in the process.

More observations of the above effect are required before any practical recommendations can be given.

IV ACKNOWLEDGMENTS

The author is indebted to his collegues: Dr. H.T. Chan for valuable suggestions made during studying the mechanical, physical and chemical properties of soil and to N. R. Laxton, W. A. Gregoriew, R. Buchanan, G. Donnelly and K. Yau for technical assistance in carrying out field experiments and in preparing this report.

Thanks are due to officers of the Radiation Protection Service of the Department of National Health and Welfare, to officers of the Radiation Protection Service and the Radiation Protection Laboratory of the Ontario Ministry of Health and to the Radiation Protection Section of the Chemistry Department of the University of Toronto for advice and assistance in using radioactive tracers in the laboratory and field.

The Chemical and Bacteriological Laboratories of the Ontario Ministry of the Environment carried out more than 5000 laboratory tests for this part of the study.

REFERENCES

1. M. Brandes, "Studies on Subsurface Movement of Effluent from Private Sewage Disposal Systems using Radioactive and Dye Tracers". Interim Report Part I, 1972, Ontario Ministry of the Environment.

2. John B. Hemwall, "The Fixation of Phosphorus in Soils". Advance in Agronomy, 9, 95-112, 1957.

3. "Agreement Between Canada and the United States of America on Great Lakes Water Quality", Ottawa, April 15, 1972.

4. W.F. Merrit, "Movement of Radioactive Wastes Through Soil". 2. Measurement of Direction and Effective Velocity of Ground Water Movement, AECL-1161, 1961. Canada

5. CJ. Velz, "Graphical Approach to Statistics" Water and Sewage Works, Reference and Data. R-106, 1952.

6. M. Brandes et al "Movement of Tracers Through Soil", Whitby Studies (to be published).

7. N.Y. State Dept. of Health, "The Long Island Ground Water Pollution Study", Final Report, April 1969.

8. J. Beek and F.A.M. de Haan, "Phosphate Removal by Soil in Relation to Waste Disposal" Proc. Intern. Conference on Land for Waste Management, Ottawa Oct. 1973. p.77.

9. Canadian Drinking Water Standards and Objectives, 1968, Department of National Health and Welfare, Canada.

10. Warren J. Kaufman, "Chemical Pollution of Ground Water", Journal AWWA, March 1974, p. 152.

11. M. Brandes, N. A. Chowdhry, and W. W. Cheng, "Experimental Study on Removal of Pollutants from Domestic Sewage by Underdrained Soil Filters", Proc. National Home Sewage Disposal Symposium, Chicago, Illinois, Dec. 9-10, 1974.

12. Guidelines and Criteria for Water Quality Management in Ontario, Ont. Ministry of the Environment, November, 1972.

13. Septic Tank Systems, Ontario Ministry of the Environment, 1974.

14. R. A. Vollenweider, "Scientific Fundamentals of Eutrofication of Lakes and Flowing Waters", with particular reference to Nitrogen and Phosphorus as Factors in Eutrophication, published by Organization for Economic Co-operation and Development", Paris, 1968.

15. T. Viraraghavan and R.G. Warnock. "Treatment Through Soil of Septic Tank Effluent" Proc. Intern. Conf. on Land for Waste Management, Ottawa, Canada, October, 1973. p.214.

16. L. T. Kurtz and S. W. Melsted, "Movement of Chemicals in Soil by Water", Soil Science, Vol 115, Nr. 3, p.231, 1973.

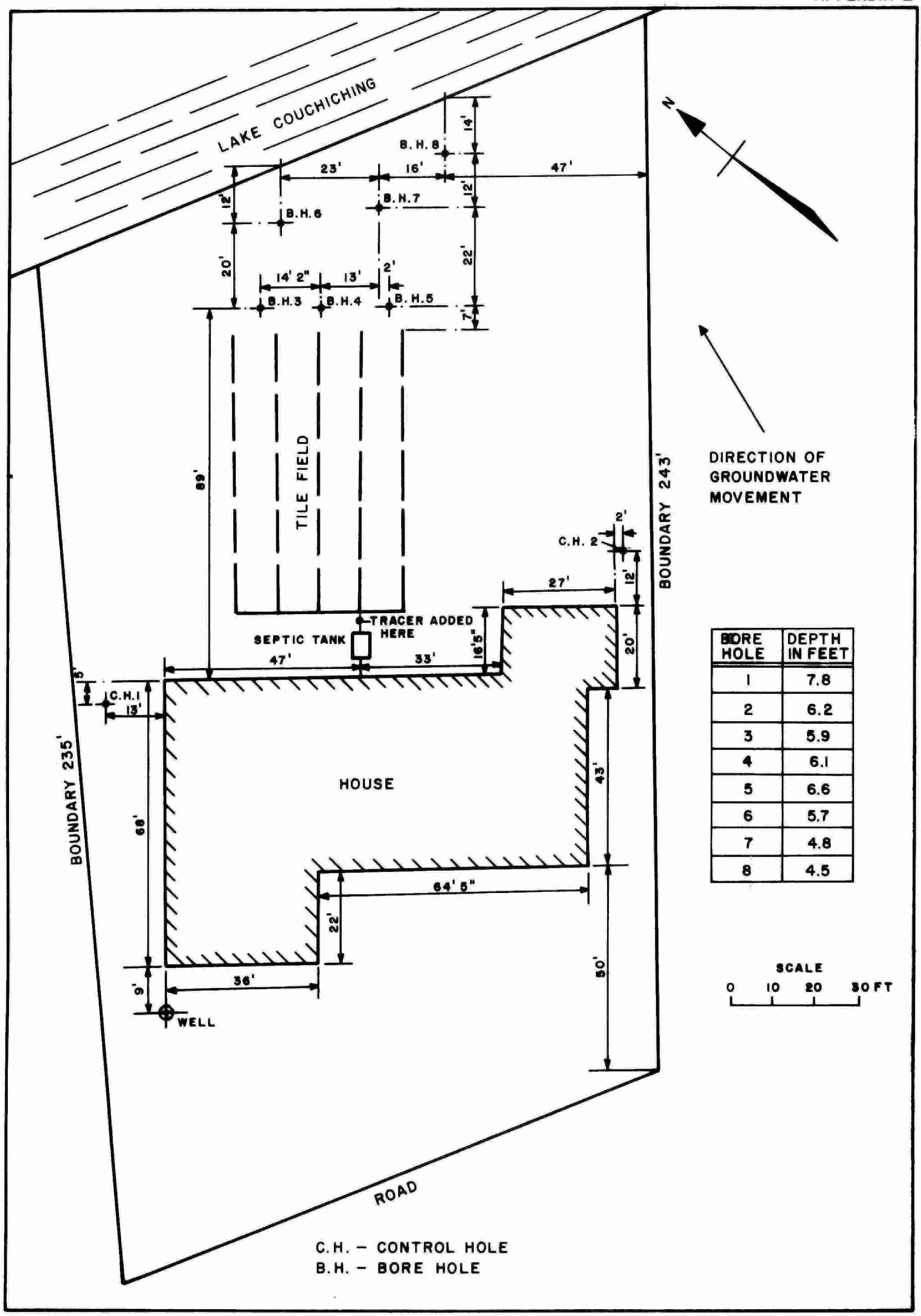
17. Guidelines for Water Quality Objectives and Standards, Techn. Bulletin No. 67, Inland Waters Branch, Department of the Environment, Ottawa, Canada, 1972.

APPENDIX I

TRACER STUDY

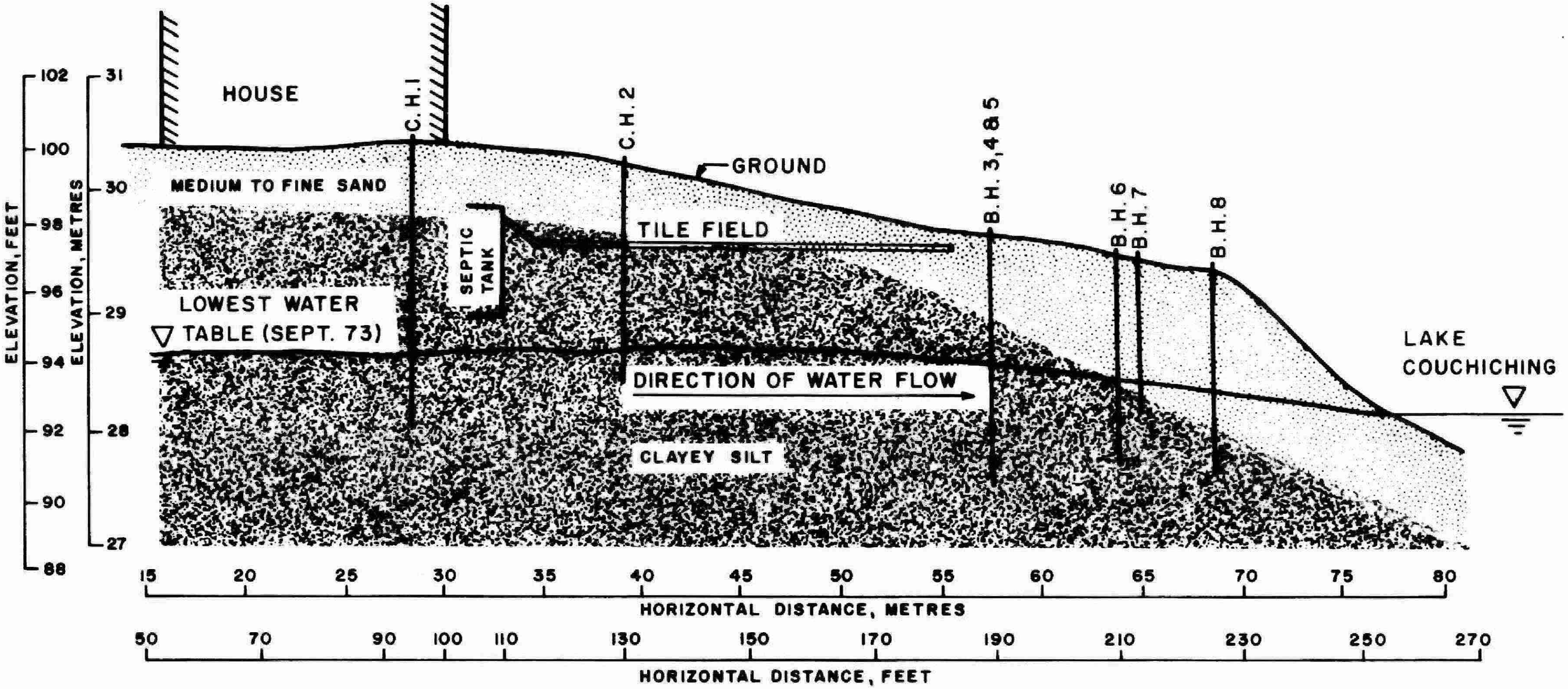
SITE PLANS

8-Figures



BORE HOLE	DEPTH IN FEET
1	7.8
2	6.2
3	5.9
4	6.1
5	6.6
6	5.7
7	4.8
8	4.5

FIG. I TRACER STUDY SITE PLAN EST. O-I LAKE COUCHICHING

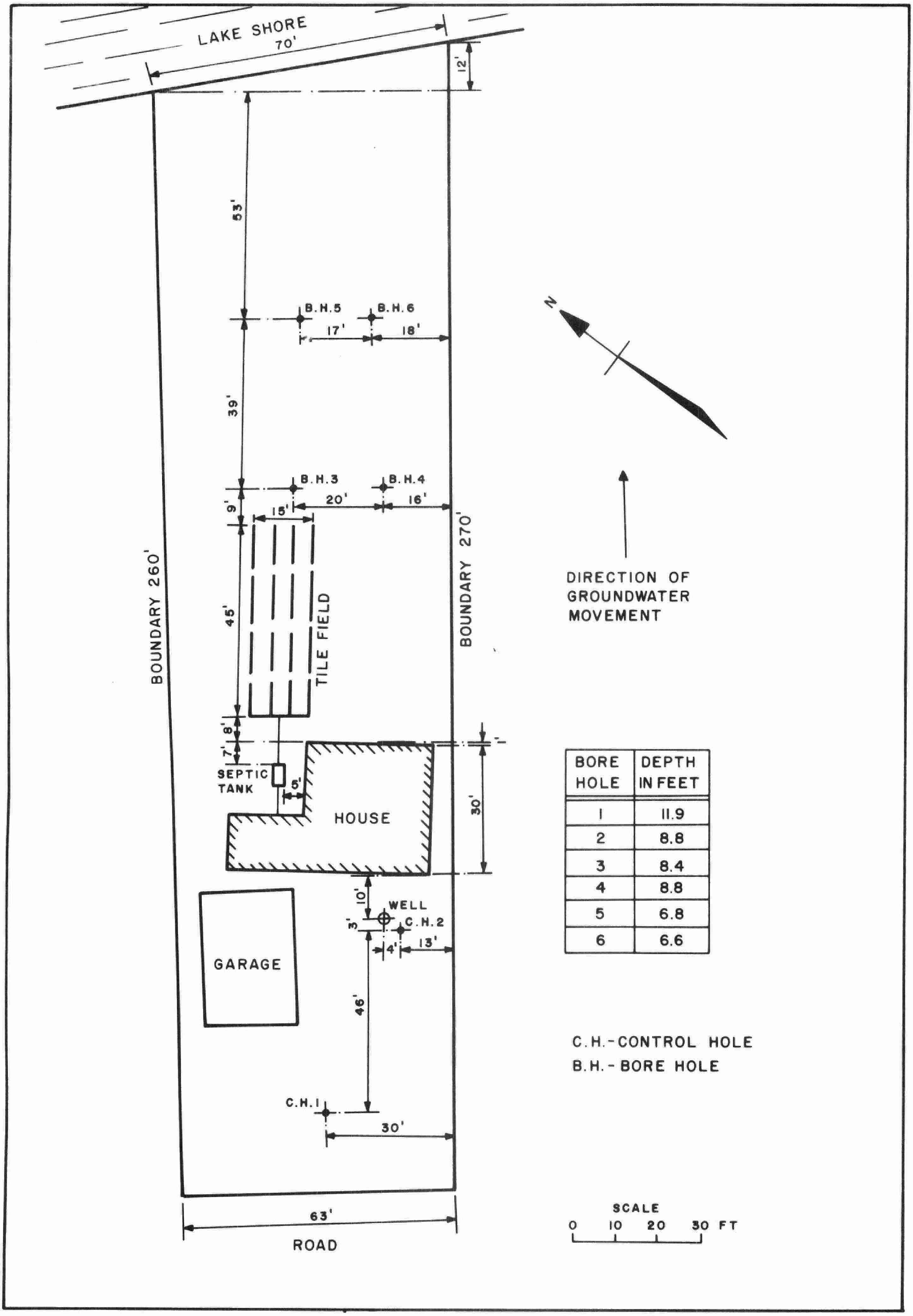


C.H. - CONTROL HOLE

B.H. - BORE HOLE

FIG. 1a GROUND PROFILE AND SOIL STRATIFICATION EST. O-1

APPENDIX I



BORE HOLE	DEPTH IN FEET
1	11.9
2	8.8
3	8.4
4	8.8
5	6.8
6	6.6

FIG. 2 TRACER STUDY SITE PLAN EST. 0-2 LAKE COUCHICHING

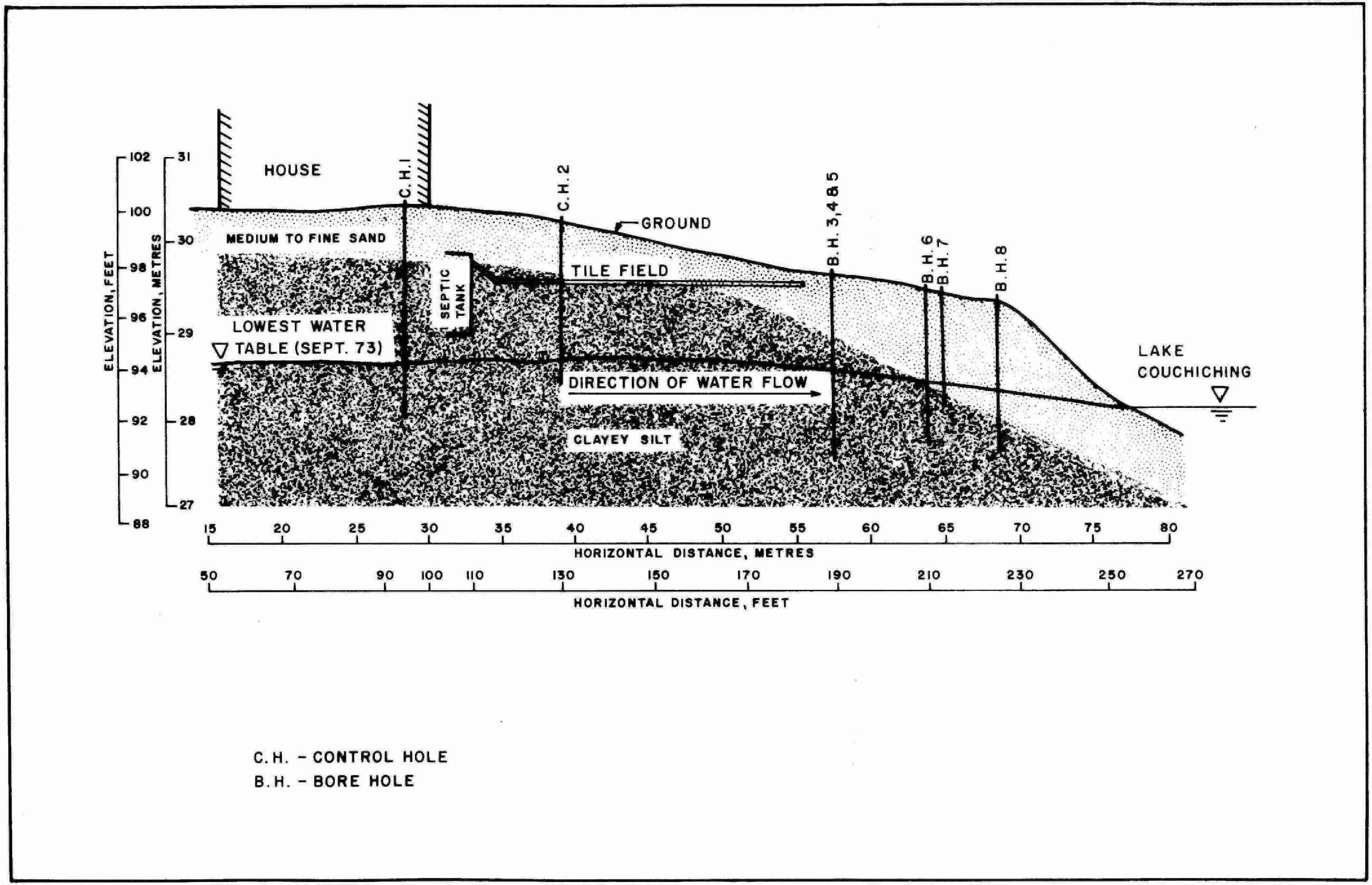
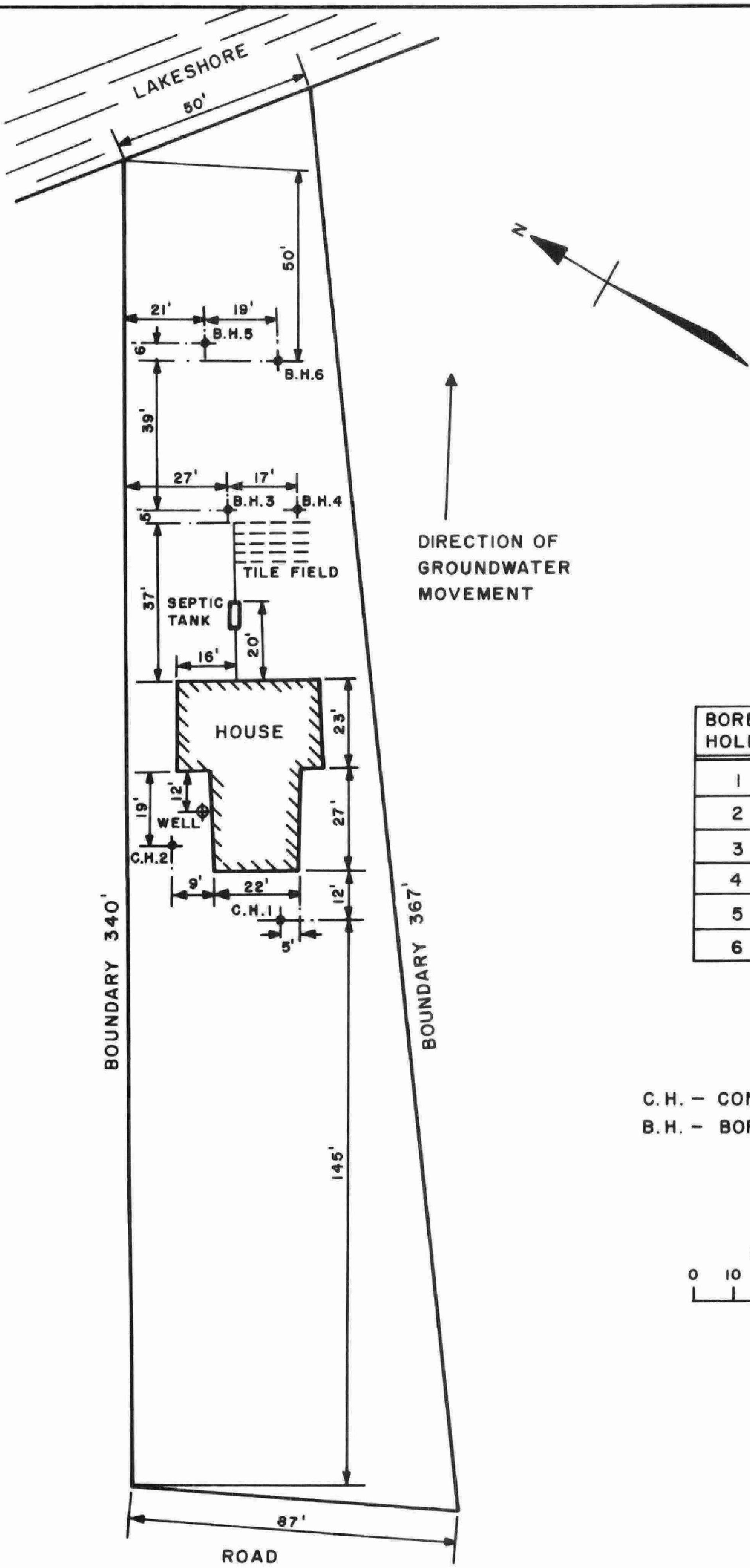


FIG. 1a GROUND PROFILE AND SOIL STRATIFICATION EST. O-1

APPENDIX I

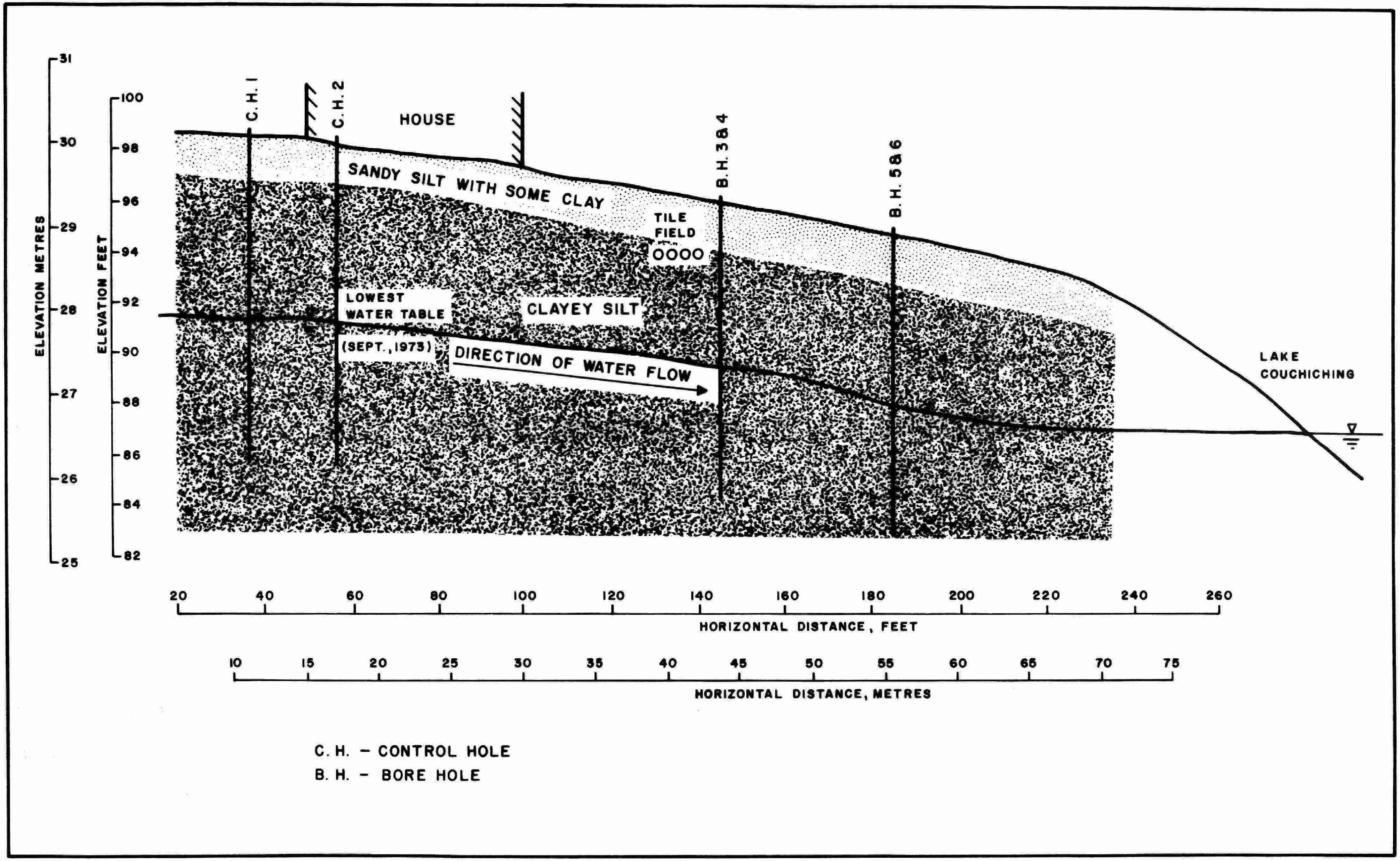


BORE HOLE	DEPTH IN FEET
1	12.9
2	12.6
3	11.6
4	11.8
5	11.9
6	11.6

C.H. – CONTROL HOLE
B.H. – BORE HOLE

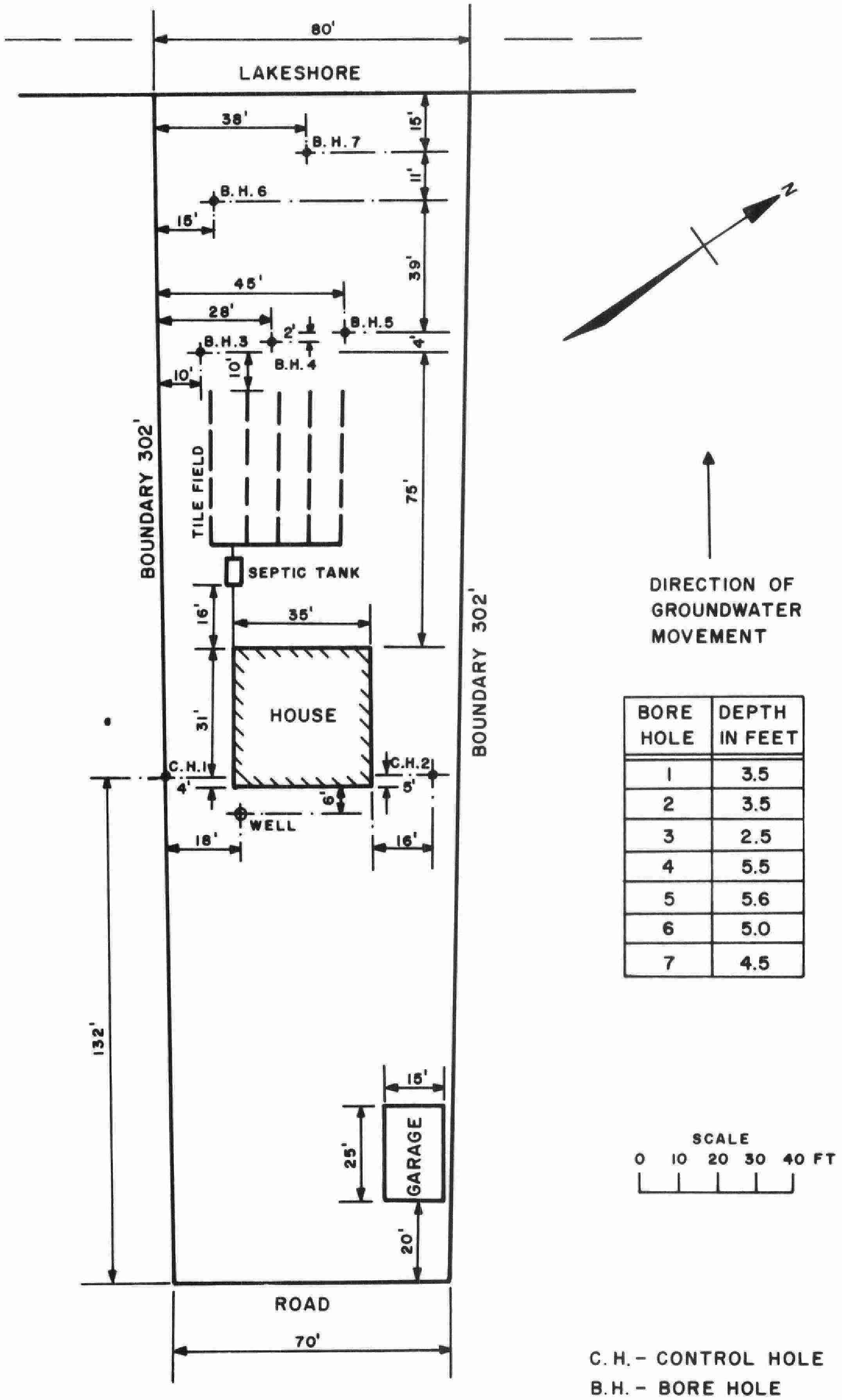
SCALE
0 10 20 30 40 FT.

FIG. 3 TRACER STUDY SITE PLAN EST. 0-3 LAKE COUCHICHING



APPENDIX I

FIG. 3a GROUND PROFILE AND SOIL STRATIFICATION EST. O-3



BORE HOLE	DEPTH IN FEET
1	3.5
2	3.5
3	2.5
4	5.5
5	5.6
6	5.0
7	4.5

FIG. 4 TRACER STUDY SITE PLAN EST. B-1 LITTLE LAKE

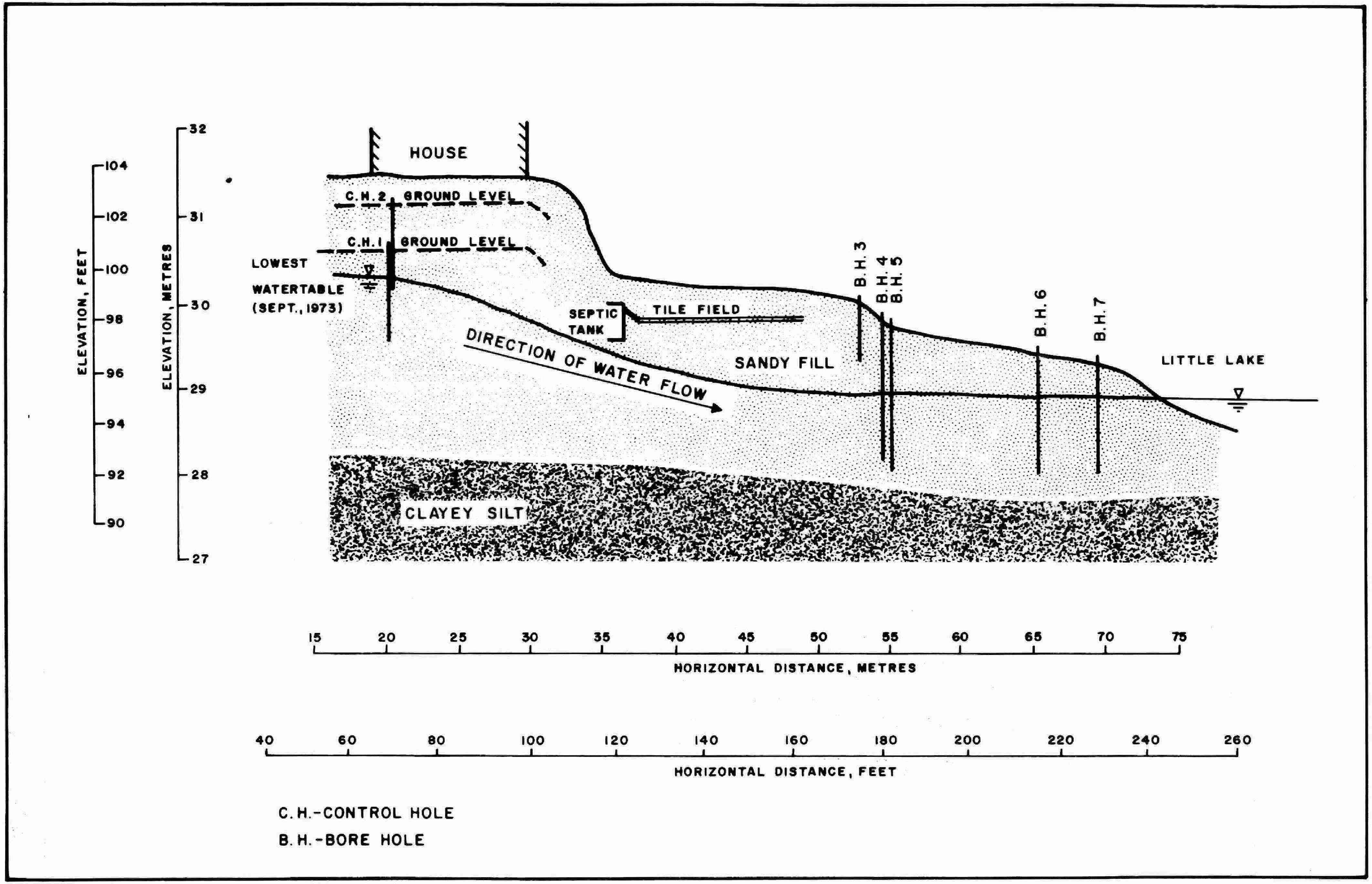


FIG. 4a GROUND PROFILE AND SOIL STRATIFICATION EST. B-1

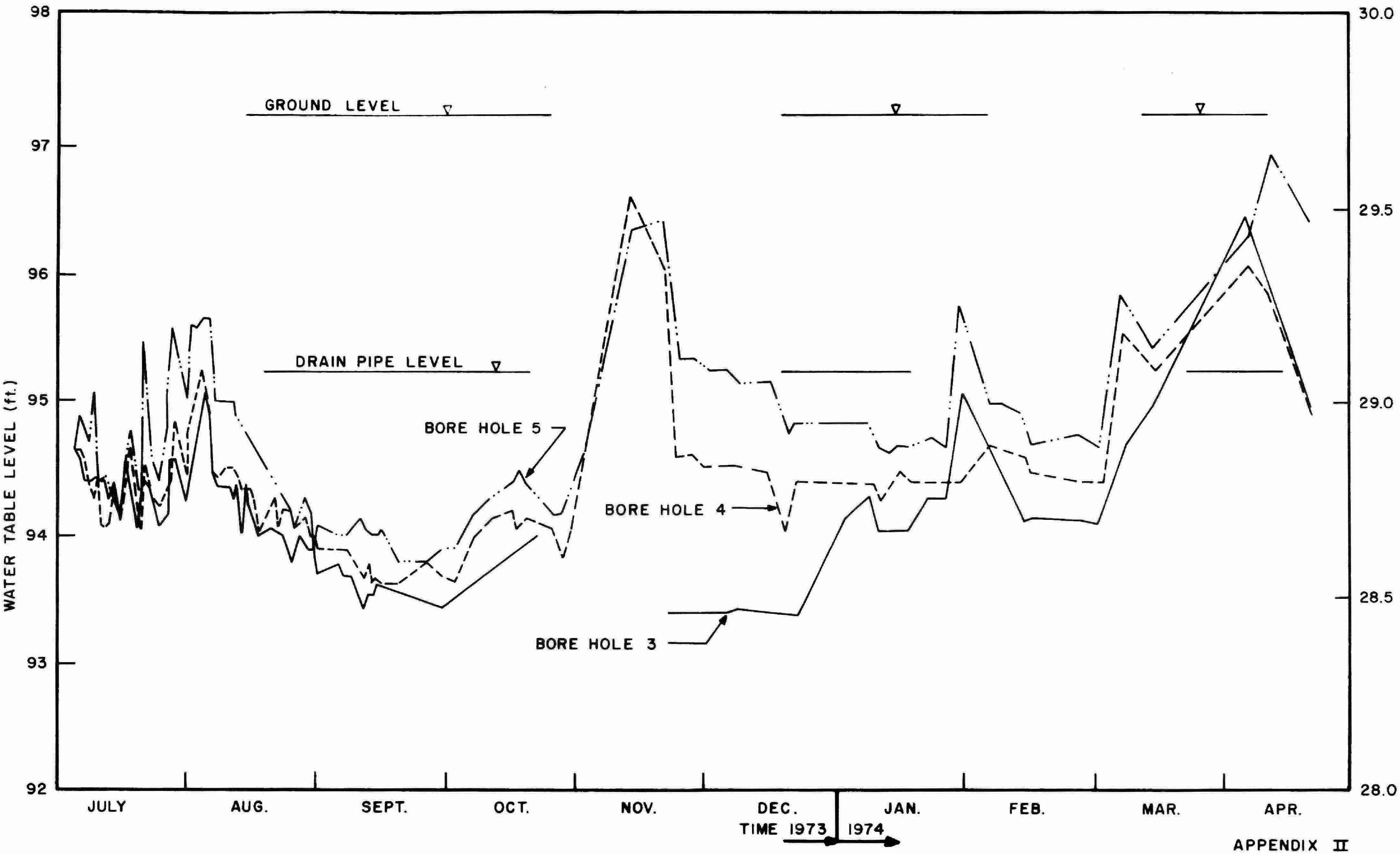
APPENDIX I

APPENDIX II

FLUCTUATION OF

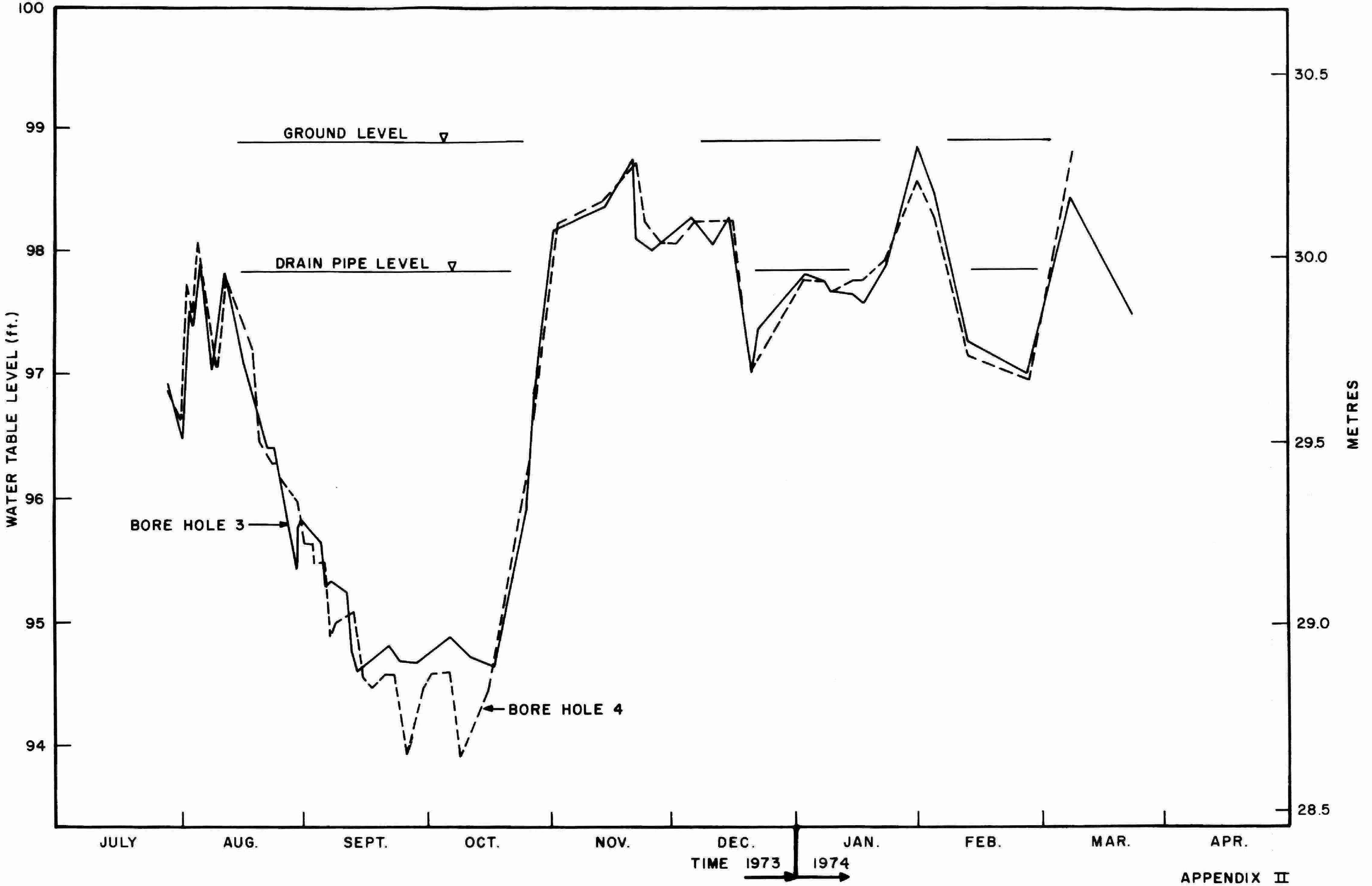
WATER TABLE

4-Figures



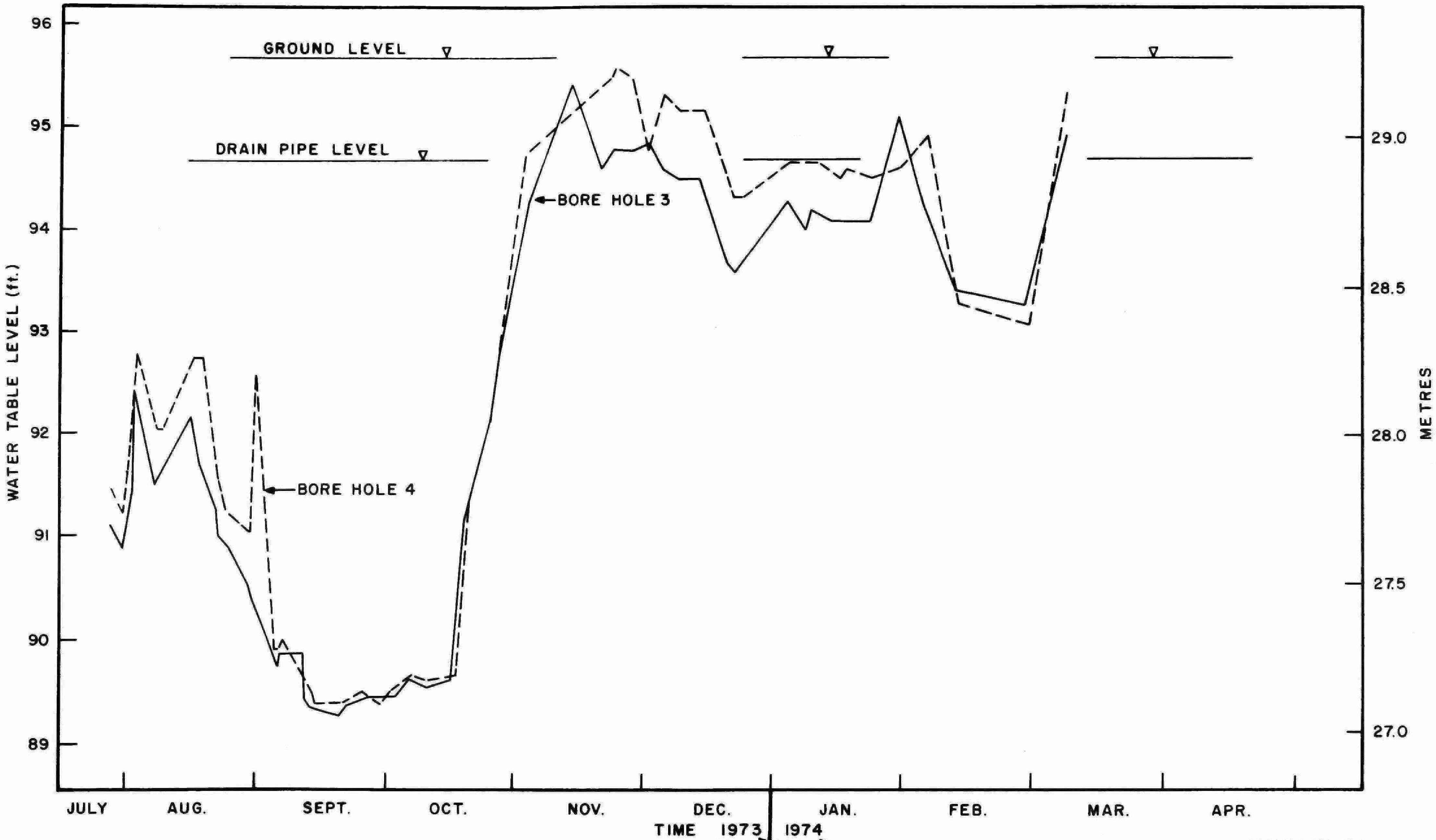
APPENDIX II

FIG. I FLUCTUATION OF WATER TABLE EST. O-I LAKE COUCHICHING



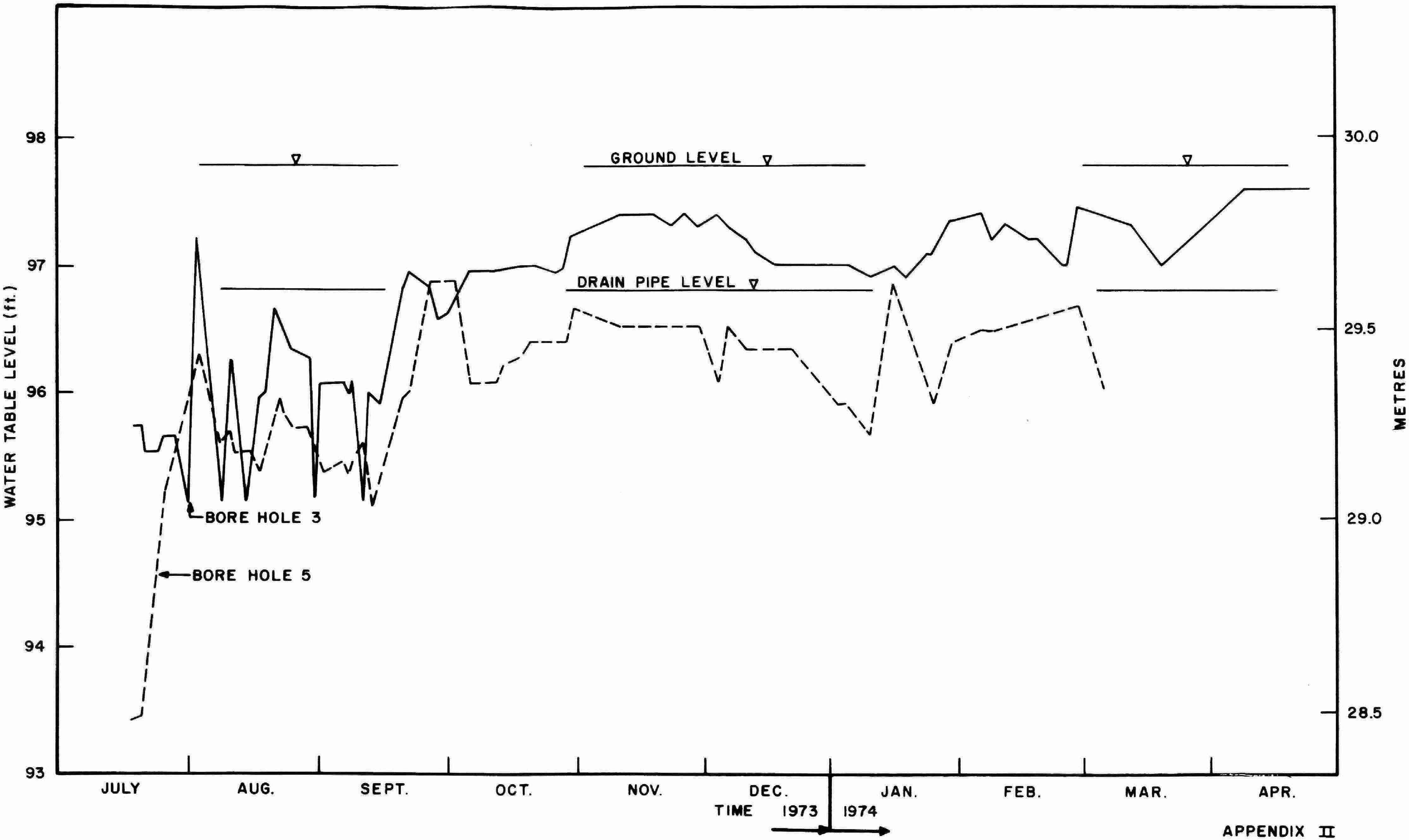
APPENDIX II

FIG. 2 FLUCTUATION OF WATER TABLE EST. O-2 LAKE COUCHICHING



APPENDIX II

FIG. 3 FLUCTUATION OF WATER TABLE EST. O-3 LAKE COUCHICHING



APPENDIX II

FIG. 4 FLUCTUATION OF WATER TABLE EST. B-1 LITTLE LAKE

APPENDIX III

CONCENTRATION

OF POLLUTANTS

4-Tables

Table 1 Concentrations of Chemical and Bacteriological Pollutants in Groundwater, Lake and Housewell Water. (Establishment 0-1 Average Data).

Sample Source	Borehole No. (see Figs. 1 & 1a of Appendix I)	Distance of Source from Tile Field	Phosphates (as P)			Nitrates (as N)		Free Amm. (as N)		Chlorides (as Cl)		BOD_5		Coliform Organisms 1000/100ml.		
			Ns	Total (mg/l)	Soluble (mg/l)	Ns	mg/l	Ns	mg/l	Ns	mg/l	Ns	mg/l	Ns	Total	Fecal
Control Hole	1	Upstream	43	0.02	0.01	45	0.81	42	0.04	34	5	27	1.0	44	0.15	*
Control Hole	2	Upstream	25	0.09	0.02	28	0.83	25	0.12	21	27	18	1.8	34	1.71	0.11
Test Hole	3	7' (2.1m)	25	0.68	0.04	27	0.07	25	0.10	21	38	17	2.4	38	0.09	*
Test Hole	4	7' (2.1m)	38	0.06	0.03	41	0.05	40	0.04	32	33	25	1.5	45	0.03	*
Test Hole	5	7' (2.1m)	38	0.35	0.05	39	0.50	39	0.23	33	36	25	4.5	42	4.73	0.92
Test Hole	6	29' (8.8m)	1	0.21	0.02	1	0.30	--------borehole dried up--------						9	0.02	*
Test Hole	7	29' (8.8m)	40	0.47	0.04	41	0.08	42	0.28	35	19	27	3.0	45	0.72	0.02
Test Hole	8	41' (12.5m)	15	0.63	0.04	15	0.11	15	0.09	14	19	7	3.2	19	1.28	0.02
	Lake	40-50' (12.2-15.2m)	19	0.03	0.02	22	0.09	19	0.05	15	14	11	2.1	20	0.06	*
Housewell		Upstream	16	0.01	0.01	16	0.03	15	0.03	10	10	6	0.4	16	*	*
	Total samples		260			275		262		215		163		312	1487	

* Coliform organisms not detected or detected in numbers smaller than 10 counts/100 ml.

Ns = number of samples.

Table 2 Concentrations of Chemical and Bacteriological Pollutants in Groundwater, Lake and Housewell Water. (Establishment 0-2 Average Data).

Sample Source	Borehole No. (see Figs. 2 & 2a of Appendix I)	Distance of Source from Tile Field	Phosphates (as P)			Nitrates (as N)		Free Amm. (as N)		Chlorides (as Cl)		BOD_5		Coliform Organisms 1000/100ml		
			Ns	Total (mg/l)	Soluble (mg/l)	Ns	mg/l	Ns	mg/l	Ns	mg/l	Ns	mg/l	Ns	Total	Fecal
Control Hole	1	Upstream	45	0.03	< 0.01	45	0.03	45	0.04	37	42	25	1.2	43	0.35	0.02
Control Hole	2	Upstream	28	0.07	0.01	30	0.09	30	0.08	24	56	15	1.3	30	0.53	0.01
Test Hole	3	9' (2.7m)	30	0.03	< 0.01	46	0.03	46	0.15	28	80	26	1.8	43	0.64	0.02
Test Hole	4	9' (2.7m)	42	0.09	0.01	45	0.06	45	0.15	38	62	26	2.1	43	0.39	*
Test Hole	5	48' (14.6m)	20	0.04	0.01	34	0.04	34	0.09	27	19	19	1.8	32	1.71	0.11
Test Hole	6	50' (15.2m)	43	0.15	< 0.01	45	0.05	45	0.02	38	23	25	2.0	43	2.14	0.22
Lake		100' (30.5m)	21	0.08	0.03	23	0.01	23	0.05	16	14	14	2.3	25	0.53	0.06
Housewell		Upstream	14	0.01	0.01	15	0.02	15	0.01	7	69?	1	1	15	0.10	*
	Total	Samples	243			283		283		215		151		274	1447	

* Fecal Coliform organisms not detected or detected in numbers smaller than 10/100 ml
Ns = No. of samples.

Table 3 Concentrations of Chemical and Bacteriological Pollutants in Groundwater, Lake and Housewell Water. (Establishment 0-3 Average Data).

Sample Source	Borehole No. (see Figs. 3 &3a of Appendix I)	Distance of Source from Tile Field	Phosphates (as P)			Nitrates (as N)		Free Amm. (as N)		Chlorides (as Cl)		BOD_5		Coliform Organisms 1000/100ml		
			Ns	Total (mg/l)	Soluble (mg/l)	Ns	mg/l	Ns	mg/l	Ns	mg/l	Ns	mg/l	Ns	Total	Fecal
Control Hole	1	Upstream	40	0.08	0.02	40	0.71	40	0.10	33	16	22	1.5	39	1.60	*
Control Hole	2	Upstream	42	0.06	0.01	42	0.42	42	0.05	35	9	23	2.8	41	4.06?	0.07
Test Hole	3	5' (1.5m)	41	0.05	0.01	42	0.57	43	0.04	36	36	25	1.8	41	0.59	0.04
Test Hole	4	5' (1.5m)	44	0.04	0.01	44	1.32	44	0.04	35	27	25	1.5	41	2.98	0.50
Test Hole	5	50' (15.2m)	42	0.03	< 0.01	41	0.09	41	0.07	34	14	23	1.0	41	0.47	0.03
Test Hole	6	44' (13.4m)	41	0.04	0.01	42	0.03	42	0.05	34	27	23	1.0	41	0.32	*
Lake		~100'(30.5m)	19	0.09	< 0.01	19	0.01	19	0.04	14	14	3	3.0	23	0.75	0.11
Housewell		Upstream	13	0.03	0.02	13	0.40	13	0.02	7	33	7	0.5	15	*	*
	Total	samples	282			283		284		228		151		282	1510	

* Faecal coliform organisms not detected or detected in numbers smaller than 10 counts/100 ml
Ns = No. of Samples.

Table 4 Concentrations of Chemical and Bacteriological Pollutants in Groundwater, Lake and Housewell Water. (Establishment B-1 Average Data).

Sample Source	Borehole No. (see Figs. 4 & 4a of Appendis I)	Distance of Source from Tile Field	Phosphates (as P)			Nitrates (as N)		Free Amm. (as N)		Chlorides (as Cl)		BOD_5		Coliform Organisms 1000/100ml		
			Ns	Total (mg/l)	Soluble (mg/l)	Ns	mg/l	Ns	mg/l	Ns	mg/l	Ns	mg/l	Ns	Total	Fecal
Control Hole	1	Upstream	31	0.15	0.05	32	0.03	32	1.54	28	117	15	1.60	4	0.15	*
Control Hole	2	control hole 2 was contaminated by accident														
Test Hole	3	10' (~3.1m)	42	1.54	0.48	46	0.40	46	2.81	43	126	31	5.30	48	0.31	*
Test Hole	4	12' (~3.7m)	3	1.14	0.09	3	1.73	3	0.77	3	50	2	11.80	5	0.28	*
Test Hole	5	14' (4.3m)	33	0.14	0.03	34	0.55	35	0.59	34	34	19	3.10	40	0.27	*
Test Hole	6	53' (16.2m)	32	0.11	0.01	33	0.05	33	0.64	29	33	16	3.00	40	0.07	*
Test Hole	7	64' (19.5m)	27	0.37	0.02	29	0.25	29	0.39	25	3	14	4.60	31	0.47	0.23
Little Lake		79' (24.1m)	11	0.07	0.01	11	0.07	11	0.06	11	21	8	3.20	12	0.89	0.03
Well		Upstream		-	-	-	-	-		-	-	-	-	2	0.04	*
	Total Samples		179			188		189		173		105		182	1016	

* Faecal coliform organism not detected or detected in numbers smaller than 10 counts/100 ml.
Ns = No. of Samples.

APPENDIX IV

(MOVEMENT OF

TRITIUM and ^{32}P)

2-Pages

MOVEMENT OF TRITIUM AND RADIOACTIVE PHOSPHORUS (^{32}P) IN SOIL

On July 9, 1973 tritium and radioactive phosphorus (^{32}P) were injected into the header between the septic tank and the tile field of Est 0-1 in following concentrations:

Tritium: 100 mCi)
) in 30 gallons (136 litres)
^{32}P: 30 mCi) of water

(Ratio$_{10}$ ^{32}P: Tritium = 0.3)

On July 22 i.e. after 13 days, the tritium was detected for the first time, in the ground water from borehole 5, the concentration of ^{32}P was not higher than that in the background samples. The effect of time on concentration of tritium and ^{32}P in the ground water of borehole 5 is shown in Fig. 1.

The first peak in concentration of Tritium, as high as 650 nCi/l, was observed on Sept. 12 i.e. after 65 days from the day the tracers were injected. The maximum concentration of Tritium, as high as 690 nCi/l, was observed on Oct. 18 i.e. after 101 days of movement.

If it is assumed that the ^{32}P moves through the soil with the same velocity as tritium, and that no ^{32}P is being fixed in the soil, the concentration of ^{32}P which should be observed in borehole 5 can be calculated. If the radioactivity of the tritium in the ground water is X nCi/l, the expected radioactivity of ^{32}P would be 0.3 X D(y) nCi/l. The factor D(y) is the natural decay factor of the isotope ($D(y) < 1$, y=number of days since the day of injection of ^{32}P), and can be calculated using the known half-life of the ^{32}P (14.3 days). The natural decay of tritium, with a relatively long half-life (12.5 years), was not taken into account in the calculation.

The radioactivity of ^{32}P in ground water samples was reported by the Radiation Protection Laboratory in cpm/100 ml (cpm=counts per minute) and that of tritium in nCi/l, (nanocuries per litre). As the rate of radioactive disintegration of one nanocurie is 37 disintegrations per second and the counting efficiency of the equipment used for counting ^{32}P radiation is 55%, the following conversion factor between the two different measurements could be used:

$$1\text{cpm} = 82 \times 10^{-5} \text{ nCi or } 1 \text{ nCi/l} = 122 \text{ cpm/100ml}$$

Thus the expected radioactivity of ^{32}P after y days would be:

$$0.3 \text{ X } D(y) \times 122 = 36.6 \text{ X } D(y) \text{ cpm/100 ml}$$

Borehole No.	Lot	No. of Days Y	D(Y)	Radioactivity of Tritium observed (X nCi/l)	Radioactivity of ^{32}P calculated (cpm/100 ml)
5	0-1	65	1/23.35	650	1019
5	0-1	101	1/133.71	690	189

The values of radioactivity of ^{32}P obtained by calculation exceed greatly the minimum detectable ^{32}P radioactivity which is 20 cpm/100 ml. In the first case the radioactivity obtained by calculation (1019 cpm/100 ml) is more than 50 times greater than the minimum detectable ^{32}P radioactivity, and in the second case (189 cpm/100 ml) i.e. 9 times greater. As the ^{32}P was not detected in the ground water it is concluded that a considerable part of the radioactive phosphorus ^{32}P was fixed in the soil and did not reach the borehole.